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The Origin of Artificial Species: Genetic Robot

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Abstract: This paper provides a basis for investigating "The Origin of Artificial Species," as a robot can be considered as an artificial creature. To design an artificial creature, its general internal architecture is presented and its artificial chromosomes are proposed as its essential components. Rity as an artificial creature is developed in a virtual world of PC to test the world's first robotic "chromosomes," which are a set of computerized DNA (Deoxyribonucleic acid) codes for creating robots (artificial creatures) that can have their own personality, and can ultimately reproduce their kind, or even evolve as a distinct species. The effectiveness of the artificial chromosomes is demonstrated by implanting the genetic code into two Ritys living in a virtual world, in order to define their personality.

Keywords: Artificial chromosome, artificial creature, genetic robot, robot genome, software robot, the origin of artificial species.

1. INTRODUCTION

Most of robot researchers have been so preoccupied with inventing robots that jog, wiggle fingers, shake hands and otherwise behave in ways that are eerily "human." As a result, they have not spent enough time for seeking the essence of "what it means to be a robot." They have been devoted to develop and to improve functionalities of robot such as intelligence, human-robot interaction and mobility, without mentioning the essence of the robot as an artificial creature.

Since "The Origin of Species" by Charles Darwin in 1859, the concept of evolution has been widely spreading around the world. Motivated by Darwin's discovery of evolution, the simulated evolution has been applied to engineering problems to get optimal solutions. Some of well-known schemes are genetic algorithm, evolutionary programming, and evolution strategies, which were developed around 1960s. As computer technology improves, these evolutionary algorithms show great performance in searching for the optimal solutions even for complex nonlinear numerical or combinatorial optimization problems. One of the applications in robotics is an optimal path planning for navigation.

As these days a robot is considered as an artificial creature, it is time to investigate "The Origin of Artificial Species" [1]. Following Richard Dawkins' claim that "we and other animals are machines created by our genes" [2], the essence of The Origin of Artificial Species must be genetic code. This paper presents a new concept of artificial chromosome as the essence to define the personality of a robot and to pass on its traits to the next generation, like a genetic inheritance. It is an essential component for simulated evolution, which necessarily defines the origin of artificial species. If we think the origin in terms of the essence of the artificial creatures, the essence should be a computerized genetic code, which determines a robot's propensity to feel happy, sad, angry, sleepy, hungry or afraid [4,5].

The first part of this paper introduces a software robot, Rity, as an artificial creature living in a virtual world of a PC [6-9]. Rity can be regarded as a genetic robot which has its own genetic information. Rity is developed to test the world's first robotic "chromosomes," which are a set of computerized DNA (Deoxyribonucleic acid) codes for creating robots that can have their own personality, and ultimately reproduce their kinds, or even evolve as a distinct species.

Using this concept, the second part of this paper proposes a way to build artificial chromosomes for genetic robots that would be capable of human-style evolution. Thus, robot genetic code should be designed to represent all the traits and personalities of an artificial creature: a manner of response to stimuli, the desire to avoid unpleasantness, to achieve intimacy and control, to satisfy curiosity or greed, and to prevent boredom, feelings of happiness, sadness,

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anger and fear to stimuli, and states of fatigue, hunger, drowsiness and so on, in order to imbue the artificial creature with "life." It can react emotionally to its environment, learn and make reasoning decisions based on an individual personality. The programmed genetic code is modeled a human DNA, though equivalent to a single strand of genetic code rather than a complex double helix of a real chromosome. The main functions of the genetic code are reproduction and evolution.

This paper is organized as follows: Section 2 introduces an artificial creature, Rity, and its internal architecture. Section 3 proposes a new concept of robot genome. In Section 4, experimental results verify the concept of robot genome which is implanted to the genetic robot, Rity. Concluding remarks follow in Section 5.

2. ARTIFICIAL CREATURE

This section introduces a software robot, Rity as an artificial creature and its internal architecture. The artificial dog, Rity, is developed to test the world's first robotic "chromosomes," which are a set of computerized DNA (Deoxyribonucleic acid) codes for creating genetic robots that can have their own personality, and ultimately reproduce their kind, or even evolve as a distinct species. Rity has internal components similar to human internal states such as motivation, homeostasis and emotion. It is an intelligent software robot that lives inside the virtual world of a computer, but interfaces with the real world through the peripheral sensors attached to the computer. It can also interact with real humans based on stimuli received from its peripheral sensors.

Rity is developed based on the internal architecture as shown in Fig. 1. The internal architecture is a general one, composed of the following five main modules:

- Perception module: perceives the environment by virtual and real sensors.
- Internal state module: defines emotion, motivation, and homeostasis.
- Behavior selection module: selects a proper behavior to the perceived information.
- Learning module: learns from interacting with people.
- Motor module: executes a behavior and expresses its emotion.

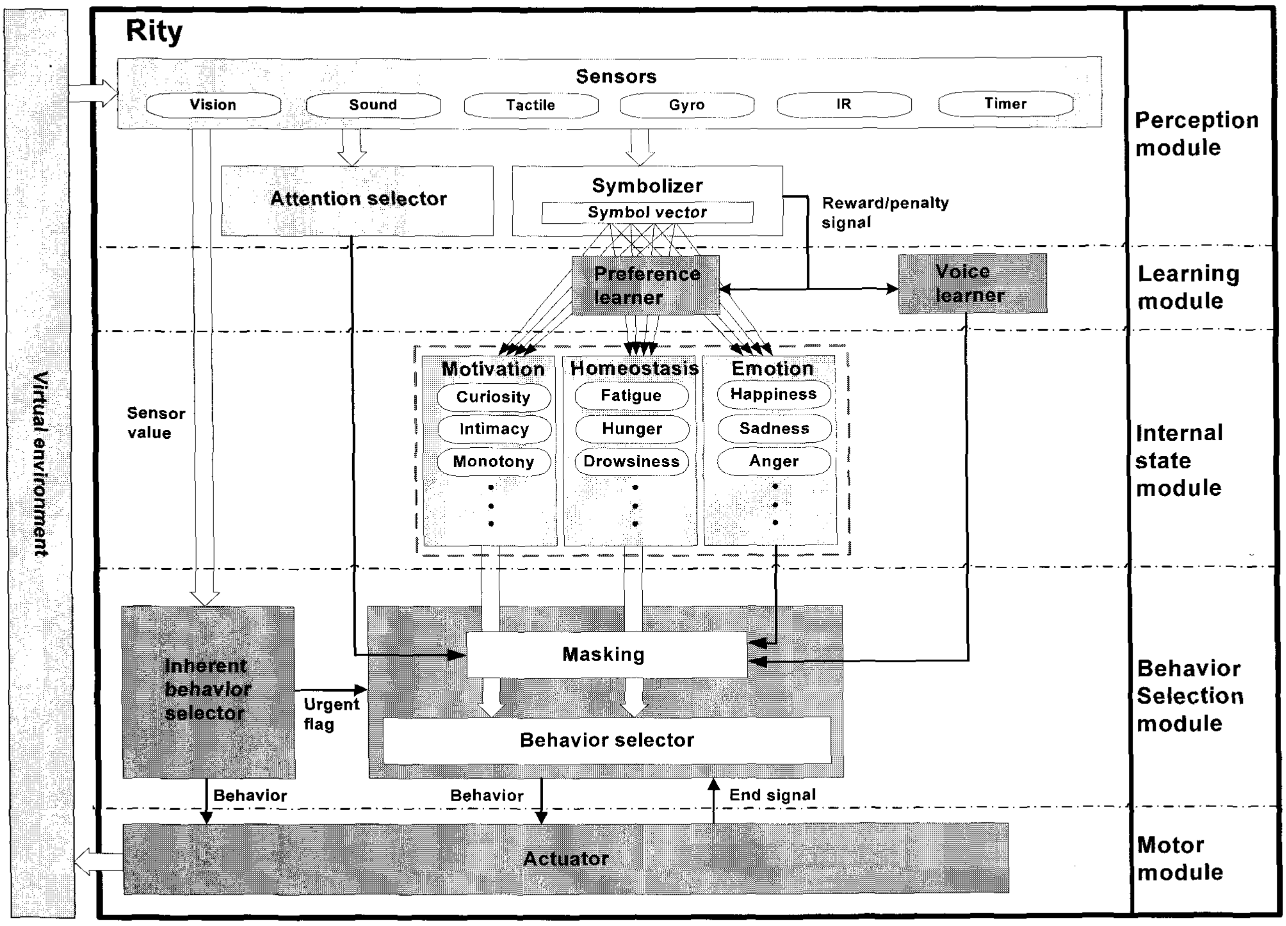


Fig. 1. Internal architecture of artificial creature, Rity.

2.1. Perception module

The perception module includes a sensor unit, a symbol unit, a sensitivity unit and an 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 light, sound, temperature, touch, vision, gyro and time. It can recognize forty-seven types of stimulus information from the sensors and the internal states through the symbolizing process for behavior selection and learning.

The symbol unit provides a vector referred to as the perception vector, A, for representing the perceived sensor information. A is defined as follows:

$$A^T = [\alpha_1, \alpha_2, \cdots, \alpha_y], \qquad (1)$$

where α_q, $q = 1, 2, \cdots, y$ is the Boolean value of qth percept and y is the total number of perceived information. The sensitivity vector P is defined as follows:

$$P^T = [\rho_1, \rho_2, \cdots, \rho_y], \qquad (2)$$

where ρ_q, $q = 1, 2, \cdots, y$ is the sensitivity of qth symbol, $0 \le \rho_q \le 1$. Consequently the stimuli constitute the stimulus vector S, defined as

$$S^T = [\alpha_1\rho_1, \alpha_2\rho_2, \cdots, \alpha_y\rho_y] = [s_1, s_2, \cdots, s_y], \qquad (3)$$

where $s_q, q = 1, 2, \cdots, y$ is the qth symbol, $0 \le s_q \le 1$.

The attention selector chooses an attentional stimulus from the stimulus vector so that it can keep attention to the stimulus without dithering easily and preventing Rity from improper behaviors.

2.2. Internal state module

The internal state module defines the creature's internal state with the motivation unit, the homeostasis unit and the emotion unit [3]. 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.

Each internal state is updated by its own weights, which connect the stimulus vector to itself and are also represented as a vector. For instance, motivation vector M is defined as

$$M^T(t) = [m_1(t), m_2(t), \cdots m_6(t)], \qquad (4)$$

where $m_k(t)$, $k = 1, 2, \cdots, 6$ is kth state in the internal state module and the number of states in motivation is six. Each motivation state is updated by

$$m_k(t+1) = m_k(t) + \{\lambda_k(\bar{m}_k - m_k(t)) + S^T \cdot W_k^M(t)\} \qquad (5)$$

where S is the stimulus vector, W_k^M is the weight matrix connecting S to kth state in the internal states module, $\bar{m}_k$ is the mean value of kth state, and λ_k is the kth state gain.

Updated equations are defined similarly for homeostasis unit using state vector $H(t)$ and the weight matrix W_k^H, and also the emotion unit using state vector $E(t)$ and weight matrix W_k^E. In this paper, the case of six states, $k = 1, 2, \cdots, 6$, in motivation, three states, $k = 7, 8, 9$, in homeostasis, and five states, $k = 10, 11, \cdots, 14$, in emotion are considered for Rity.

2.3. Behavior selection module

The behavior selection module is used to choose a proper behavior based on both Rity's internal state and 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:

1) Determine a temporal voting vector, V_t using M and H.
2) Calculate a voting vector V by masking V_t using attention, command and emotion masks.
3) Calculate a behavior selection probability, $p(b)$, using V.
4) Select a proper behavior b with $p(b)$ from a selection of various behaviors.

2.3.1 Determination of the temporal voting vector V_t

The first step requires the determination of the temporal voting vector. For Rity, there are six motivation states and three homeostasis states. The temporal voting vector is calculated as follows:

$$\begin{aligned} V_t^T &= (M^T D_M + H^T D_H) \\ &= [v_{t1}, v_{t2}, \cdots, v_{tz}], \end{aligned} \qquad (6)$$

where z represents the number of behaviors. v_{tr}, $r = 1, 2 \cdots, z$, is the temporal voting value, $6 \times z$ matrix D_M, and $3 \times z$ matrix D_H are the behavioral weight matrices connecting motivation and homeostasis to behaviors, respectively.

2.3.2 Calculation of the voting vector

Three masks are applied to the temporal voting vector, V_t. There are 'masking for attention,' 'masking for command,' and 'masking for emotion,' which assist Rity in selecting more appropriate behaviors and avoiding more unusual behaviors.

An attention masking matrix $Q^a(a)$ is obtained by the attention stimulus, a. Each attention stimulus has its own masking value and the matrix is defined as diagonal matrix with diagonal entries $q_1^a(a)$, $q_1^a(a)$, q_2^a $\cdots$ $q_z^a(a)$ where z is the number of behaviors, $q^a(\cdot)$ is the masking value, and $0 \leq q^a(\cdot) \leq 1$. Command and emotion masking matrices, $Q^v(c)$ and $Q^e(e)$ where c is the voice command and e is the dominant emotion, are defined in the same way.

From these three masking matrices and the temporal voting vector, the behavior selector obtains a final voting vector as follows:

$$\begin{aligned} V^T &= V_t^T Q^a(a) Q^v(c) Q^e(e) \\ &= [v_1,\ v_2,\ \cdots,\ v_z], \end{aligned} \tag{7}$$

where v_r, $r = 1, 2, \cdots, z$, is the rth behavior's voting value. By using masking matrices, emotion as well as an external input can be taken into consideration on selecting a behavior because the emotion masking matrix $Q^e(e)$ is equal to the behavioral weight matrix connecting emotion to behaviors, D_E.

2.3.3 Calculation of the behavior probabilities

The selection probability $p(b_k)$ of a behavior, b_k, $k = 1, 2, \cdots, z$, is calculated from the voting values as follows:

$$p(b_k) = \frac{v_k}{\sum_{r=1}^{z} (v_r)}. \tag{8}$$

2.3.4 Selection of the proper behavior

By using the proportional selection mechanism based on the probability of each behavior, the behavior selector can provide diverse behaviors. The inherent behavior selector makes up for the weak point in the behavior selector. For instance, as soon as an obstacle like a wall or a cliff is found, the inherent behavior selector makes Rity react to this situation immediately.

In addition to behaviors, Rity can have five facial expressions such as happiness, sadness, anger, fear and neutral. The selection of facial expression is based on the dominant emotion at that moment.

2.4. Learning module

To enable an artificial creature to be intelligent and interactive with both human beings and its environment, the learning module is incorporated into its architecture. The learning module in Rity is composed of two distinct units: a preference unit and a voice learning unit.

The preference learning unit enables the artificial creature to be taught by its master by rewarding or punishing the creature in various situations. Internally, the unit causes the connected weights associated with the internal states to be adjusted whenever a reward or a punishment is administered. Externally, this is reflected in the artificial creature's personality as it generates likes and dislikes for various objects and situations in its external environment.

The voice learning unit teaches the artificial creature to respond with an appropriate behavior when instructed. This is an important aspect of the interaction required between artificial creature and its master. Internally, the unit adjusts weights associating voice commands with behaviors. If the creature responds correctly to a voice command, weight associating behavior and command strengthens, while the others weaken.

However, the learning process requires much time and because of the artificial creature's probabilistic internal model, it may result in erroneous behaviors that are completely unacceptable for the command given. To increase the learning rate and the reliability of the probabilistic response, similar behaviors are classified into subsets. Correct responses to a command strengthen weights for the entire subset rather than individual behaviors.

Using these learning units, an artificial creature may be trained in the same manner as a real pet would be trained. Refer to [7] for a detailed description of the learning module.

2.5. Motor module

The motor module incorporates virtual or real actuators to execute selected behavior in the virtual 3D environment.

All the modules are embodied in Rity, which is a 3D virtual pet with 12 degrees of freedom. It is developed in Visual C++ 6.0 and OpenGL, and works well on Pentium III machines or above. Fig. 2 is a photograph of computer screen showing Rity in a virtual 3D environment. The small window at the bottom right of the figure shows the visual information in the form of a recognized face. The window at the top right shows a graphical representation of Rity's internal states.

3. ROBOT GENOME

This section presents a way to build an artificial creature that would be capable of human-style evolution. As is well known, there is no one gene - one trait relationship in naturally evolved system because of the pleiotypic and polygenic nature of the genotype, where pleiotypic nature has the effect that a single gene affects multiple phenotypic characters and polygenic nature has the effect that a single phenotypic character is affected by multiple genes.

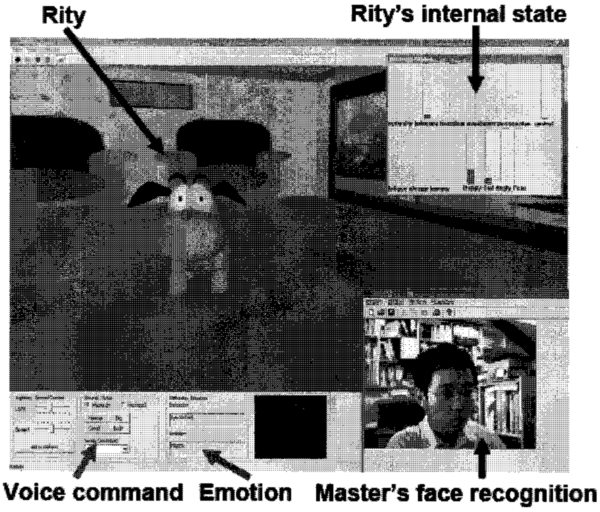


Fig. 2. Rity and its virtual 3D environment.

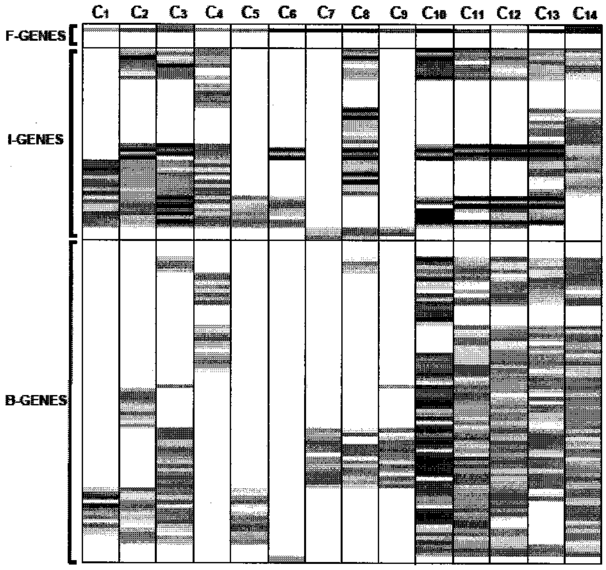


Fig. 3. Artificial chromosomes of Rity.

This means a single genetic change can affect every phenotypic characteristic.

To reflect this nature, unlike previously devised methods that associated stimuli with responses, Rity's chromosomal coding contains a sophisticated weighting system provided in the internal architecture (Fig. 1). Internal relationships created by the weighting system allow Rity to be an individual capable of more than purely mechanistic response. Also it has a kind of programmed favoritism for one subtle shade of emotional or rational response, over another.

Rity has fourteen artificial chromosomes by which its traits can be passed on to its offspring. It perceives 47 different types of stimuli and can respond with 77 different behaviors as its responses. Fig. 3 shows its 14 chromosomes, where chromosomes C_1-C_6 are related to motivation, C_7-C_9 to homeostasis, and C_{10}-C_{14} to emotion. Also, motivation is composed of six states such as curiosity, intimacy, monotony, avoidance, greed, and desire to control. Homeostasis includes three states such as fatigue, drowsiness, and hunger and emotion includes five states such as happiness, sadness, anger, fear, and neutral. Each one of total 14 states is encoded in the corresponding chromosome. For example, chromosome C_1 has information on curiosity; chromosome C_2 has information on intimacy, etc. Each chromosome C_K, $k = 1, 2, \cdots, 14$, consists of three kinds of genes: F-genes X_k^F, I-genes X_k^I, and B-genes X_k^B, defined as

$$C_k = \begin{pmatrix} X_k^F \\ X_k^I \\ X_k^B \end{pmatrix} \tag{9}$$

with

$$X_k^F = \begin{pmatrix} x_1^F \\ x_2^F \\ \vdots \\ x_p^F \end{pmatrix}, X_k^I = \begin{pmatrix} x_1^I \\ x_2^I \\ \vdots \\ x_q^I \end{pmatrix}, X_k^B = \begin{pmatrix} x_1^B \\ x_2^B \\ \vdots \\ x_n^B \end{pmatrix}, \tag{10}$$

where p, q, and n are total numbers of F-genes, I-genes, and B-genes in a chromosome. In Rity, $p = 5$, $q = 47$, and $n = 77$.

Consequently, a robot genome G, a chromosomal set with genetic codes determining Rity's personality, is defined as

$$G = [C_1 \ \ C_2 \ \ \cdots \ \ C_{14}]. \tag{11}$$

F-genes represent fundamental characteristics of Rity, including genetic information such as volatility, initial and mean values, $\bar{m}_k$ in (5), and the decay rate of each internal state. Volatility determines whether the internal state is volatile or non-volatile since operating point in time. $\bar{m}_k$ is the value to which the internal state converges without any stimuli. A high value means high desire to enhance corresponding internal state. F-genes can also include sex, life span, color, and so on to define its fundamental nature.

I-genes include genetic codes representing its internal preference by setting the weights of $W_k^M(t)$ in (5). Theses genes shape variety of the internal state affected by stimuli and have information on whether the stimulus satisfies, amplifies, or has nothing to do with the internal state. After the birth, the preference can be trained on-line by adapting the weights like pet training.

B-genes include genetic codes related to output behavior by setting the weights of D_M and D_H in (6), and D_M in (7). These genes are responsible for behavior selection, its frequency, and its activation level based on the internal state. They also include masking information which prevents Rity from doing unnecessary behaviors and emotional expression.

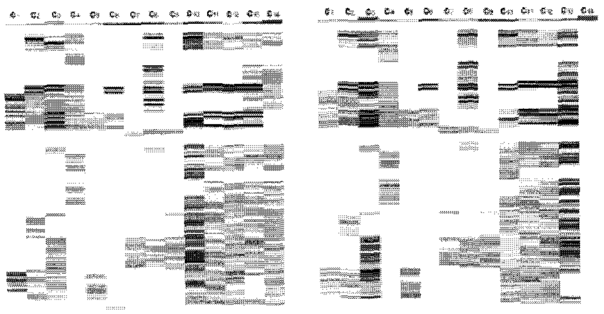
4. IMPLEMENTATION OF GENETIC ROBOT

A genetic robot is defined as an artificial creature or a robot that has its own robot genome. The concept of the genetic robot is verified by implanting the genetic codes into Ritys. The genes in Fig. 3 are originally represented by real numbers: values of F-genes range from 1 to 500, I-genes from -500 to 500, and B-genes from 1 to 1000. Like a DNA analysis, these genes are normalized to brightness values from 0 to 255 in the figure, which are expressed as black-and-white rectangles. The darker the color is, the higher its value is. In addition to the positive normalization, I-genes may have negative values and be normalized as red-and-black rectangles in the same manner.

Fig. 4 shows two different chromosome set of "Ritys." As their genetic codes are different, no two Ritys react the same way to their surroundings as shown in Fig. 5. In the figure, there are two Ritys in the local space. They look alike but have different characteristics. If the user gives the same stimulus to the two Ritys, for example, clicks once to pat or twice to hit, each Rity will react differently because of their different characteristics. The figure shows the results of the experiment after applying 10 instances of patting or clicking, on both Ritys A and B. It shows the changes in internal state, facial expression and their behavior.

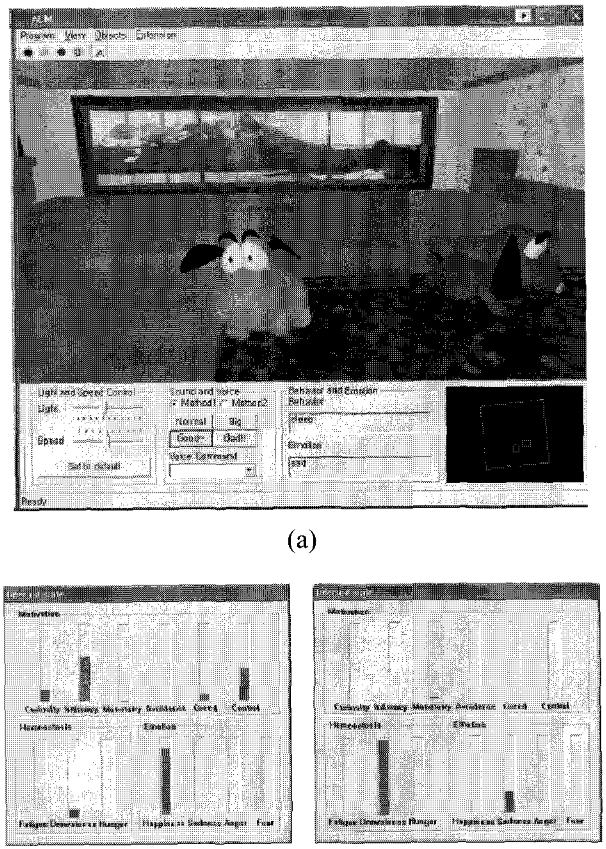
The dialog bars in Fig. 5(a) show the status of Ritys. As the amount of curiosity, intimacy and happiness increases, Rity A starts moving around with a happy face. On the other hand, in the case of Rity B, the drowsiness increases its sadness and eventually puts it to sleep. Fig. 5(b) and Fig. 5(c) show a comparison of the internal states of Ritys A and B. It has been observed that various stimuli, such as loud noises or variations in lighting conditions, affect the emotional state and behavior of each Rity, depending on its individual characteristics.

This paper is to provide a basis for evolution of the genetic robot. The evolution can be done by genetic operators such as crossover and mutation operators and by defining the fitness function for natural selection. One suggestion of implementing the crossover operator is for it to be performed between parental genes of the same kind (F-, I-, and B-genes), length, and chromosomal order. Mutation operator can be implemented in the same manner as the other evolutionary algorithms.



(a) (b)

Fig. 4. Two different chromosome set of "Ritys": (a) chromosome set of Rity A and (b) chromosome set of Rity B.



(a)

(b) (c)

Fig. 5. Genetic robot A and genetic robot B in a virtual space (a) Rity A and Rity B, (b) Internal state of Rity A, and (c) Internal state of Rity B.

5. CONCLUSIONS

This paper has proposed a new concept of artificial chromosome to investigate "The Origin of Artificial Species" and to define genetic robot, which has its own genome. The robot genome has been implanted to Rity, an artificial creature, living in a virtual 3D world of a computer. The result has shown feasibility that robot would have their own personality. The artificial chromosomes will ultimately lead the genetic robot to reproduction and evolution. Current version is equivalent to a single strand of genetic code of real numbers rather than the complex double helix of a real chromosome.

One of future works is on the equivalent of X and Y chromosomes that would confer sexual characteristics. Thus, if male and female like each other, they could have their own children. Also the software chromosomes will be implanted in a mobile robot so that they will imbue the robot with life.

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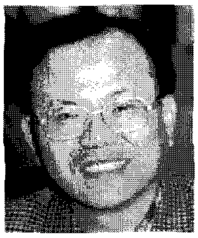

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