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TOWARDS EVOLVABLE EXTERIOR: COLOR PATTERN EVOLUTION BASED ON THE PREDATOR-PREY INTERACTIONS

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Abstract

The paradigm "System Life" is an innovative competence to create harmony in the world of natural entities and artifact-systems interacting each other. We propose a new concept "Evolvable Exterior" as one of the essential elements that make the System Life competence embody into artifact-systems. This paper reports our efforts to investigate the feasibility of the evolution of color patterns on the surfaces of artifact-systems driven by the predator-prey interactions based on the methodology of artificial life approach.

1. Introduction

The artifact-systems created by humans will be sure to generate deeper interactions with the surrounding natural world in the coming century. "System Life" seems to be a strong candidate as a leading paradigm which creates harmony in the world of natural entities and artifact-systems interacting each other, and avoids the conflicts between human-machine interactions. This paper proposes a new concept named "Evolvable Exterior" as one of the essential elements that make the System Life competence embody into artifact-systems.

Natural scenes that are composed of plants, animals and natural entities, are very beautiful, and give mental comfort to us, humans. They have been created not only by random dynamics in a short term but also by evolutionary dynamics in a long term. We have been focusing on the predator-prey interactions as an origin of dynamics producing transition of color patterns[1].

Predator-prey interactions can be considered one of the driving forces in evolution. Successful predation events characteristically follow a sequence of six stages – encounter, detection, identification, approach, subjugation and consumption[2]. Prey wish to interrupt this sequence as soon as possible by means of defences, whereas predator wish to reach the conclusion quickly by means of counter-defences. Predation and predator defence go back at least to the early Cambrian[3], so we can assume that prey have evolved many methods to terminate predation as early as possible. Among many means of defence and counter-defence, color patterns on their epidermis play an important role in the detection and identification stages. For example, some species match the color and pattern of the background to avoid detection by predator (crypsis), and some species bear special resemblance to inedible objects (masquerade) or distasteful species (mimicry)[4]. Therefore, the epidermis patterns of animals and plants are functional and dynamic in this context. At the same time, it is true that they constitute beautiful and harmonious scenes, as a result, and we feel comfortable in natural scenes.

Motivated by above-mentioned consideration, we have started investigating the feasibility of the evolution of color patterns on the surface of artifact-systems using the dynamics of predator-prey interactions observed in nature. This paper describes our efforts to abstract the evolutionary mechanism of color pattern generation and color pattern recognition, and to construct a model in which coevolutionary dynamics based on the predator-prey interactions automatically generates such various color patterns as observed in nature one after another in the context of artificial life approach. We also discuss how we are attempting to apply and extend the model to a real-world in order to embody the concept of System Life.

2. Model

2.1 Outline

In the model, the world has several species among which there are predator-prey relationships. Each organism of all species has a pattern development system and a pattern recognition system. Pattern development system, which can be considered a two-dimensional extension of the 0L-system by Lindenmeyer[5], has five generative grammars, which are inherited to offspring by genetic operations. One of the five grammars develops the color pattern on its epidermis. The other four grammars develop color patterns for its predator, its prey, its kindreds and the background, respectively, which are compared with the color patterns on the epidermis of the organisms it has encountered, to detect and identify its species in its recognition system. Encountered organisms recognize each other, and both organisms are rewarded, according to the results of their recognition. Another pair is then selected and rewarded again. In this manner, every combination among all the organisms and the background is selected once. Next generation is created by roulette selection based on their scores. Then, four types of mutation are performed on their production rules of the selected organisms. Fig. 1 illustrates the structure of the model, and Fig. 2 shows it's algorithm.

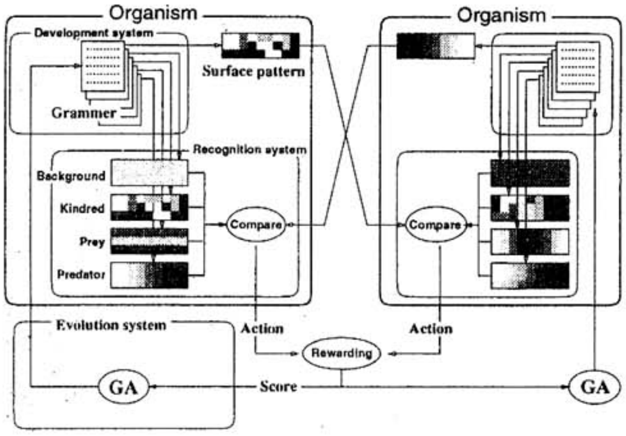

Fig. 1 Evolutionary model for color pattern generation.

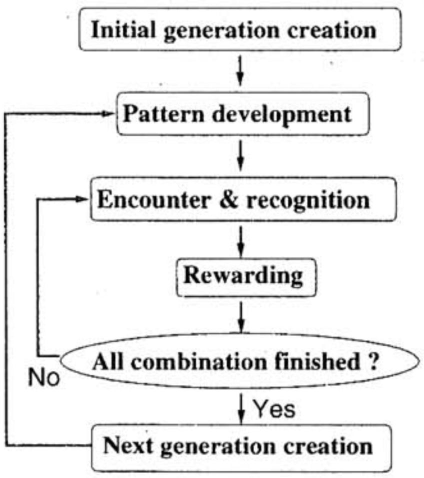

Fig. 2 Algorithm of the model.

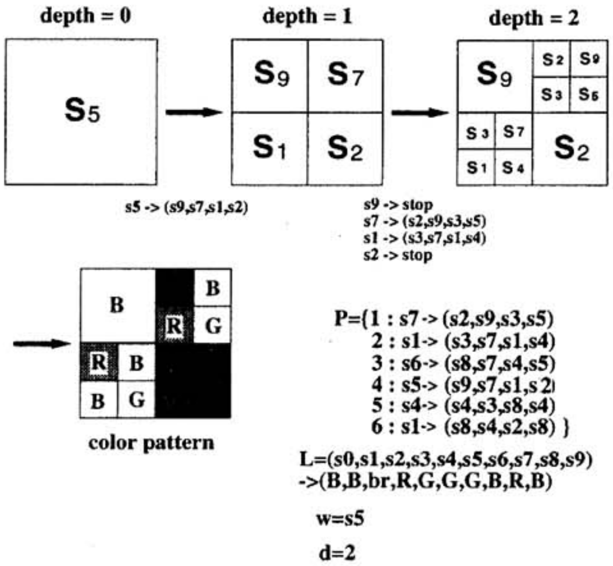

Fig. 3 An example of pattern development.

2.2 Pattern develop system

Color patterns are mosaics of square patches which vary in size and color, generated by the generative grammar $G = \{\Sigma, C, P, L, \omega, d\}$. All organisms have same set of symbols Σ, which represent the state of the squares, and same set of colors C, which are finally assigned to all the square patches:

$$\Sigma = \{s_1, s_2, \cdots, s_n\}$$
$$C = \{color_1, color_2, \cdots, color_m\}$$

Production rules P, which is a finite set of ordered rules, color mapping rule L, which are the function from the symbol set Σ to the color set C, and start symbol ω, are peculiar to each organism:

$$\begin{aligned} P = \{1 : a_1 &\Rightarrow (b_{11}, b_{12}, b_{13}, b_{14}) \\ 2 : a_2 &\Rightarrow (b_{21}, b_{22}, b_{23}, b_{24}) \\ &\vdots \\ k : a_k &\Rightarrow (b_{k1}, b_{k2}, b_{k3}, b_{k4})\} \end{aligned}$$

$$L = (s_1, s_2, \cdots, s_n) \rightarrow (c_1, c_2, \cdots, c_n)$$

where a_i,b_{ij}, and ω are the member of Σ, and c_i are the member of C.

At first, there is one square ω, and by applying a production rule, square is replaced by 4 squares. When multiple rules are possible to be applied, the preceding rule in the rule set is adopted. When more than one square in the current color pattern can be applied, all the replacements are done at the same time. All the symbols in the pattern are assigned colors according to the color mapping rule L, after d (depth) times of this processing are finished. Fig. 3 shows an example of color pattern generation, where $d = 2$.

2.3 Pattern recognition system

Each organism detects the other organism which it has encountered and identifies it as a prey, a predator, a kindred or the background by comparing the color pattern of the other organism with the pattern for recognition which were generated by its production rules. To identify the other organism as the background means that the organism can recognize the background correctly, or cannot detect the other organism. A very simple method is adopted for recognition in this paper, which is realized by roulette selection based on number of square patches in minimum size which are coincident in colors (Fig. 4).

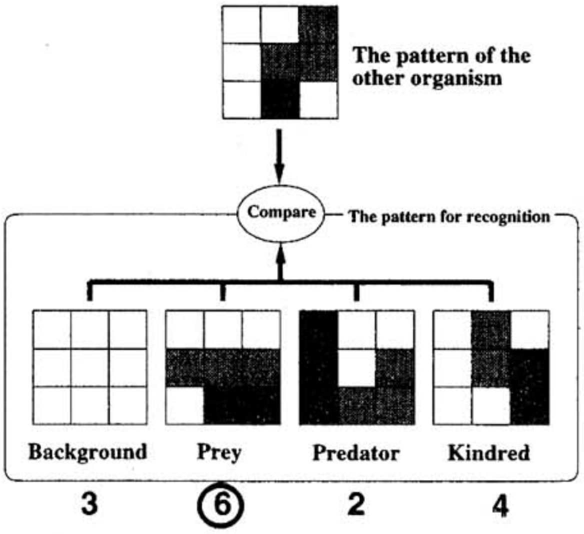

Fig. 4 An example of pattern recognition.

2.4 Rewarding

First, a pair of the organisms is selected over the organisms, as the first stage of the predation sequences. As the detection and identification stage, both of them look the other's color pattern and recognize as one of the four candidates – the background, a prey, a predator, or a kindred. Both organisms are then rewarded, according to the results of their recognition. The scoring points are defined such as Table 1. Fig. 5 shows an example of rewarding. Table 1 a) shows the case that the relationship between the organism and the other is prey-predator, and if the organism identifies the other organism as a prey and the other organism identifies it as a prey, the organism rewarded with -6. The rewarding function is determined in consideration of following characteristics:

- The reward is higher, when an organism has recognized the other organism correctly.
- In the case that the other organism has recognized it incorrectly, the reward is lower, when the other organism is a kindred, and the reward is higher, when the other organism is not a kindred.

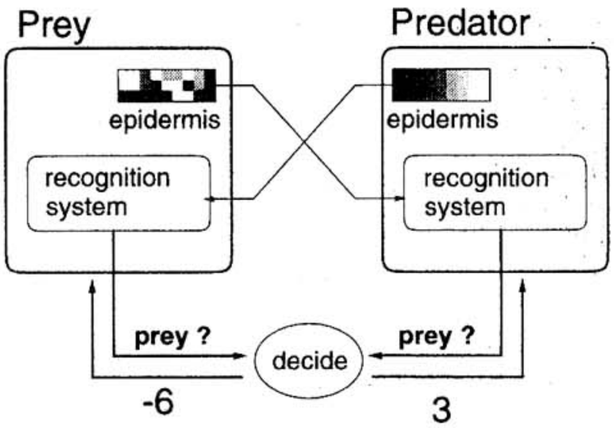

Fig. 5 An example of rewarding.

Table 1. Rewarding function.

a) (Prey ⇒ Predator)

	Background	Prey	Kindred	Predator
Background	−1	−4	−1	1
Prey	−1	−6	−2	0
Kindred	−1	−6	−2	0
Predator	2	0	1	3

b) (Predator ⇒ Prey)

	Background	Prey	Kindred	Predator
Background	−1	0	0	−4
Pred	2	3	3	0
Kindred	−1	0	0	−4
Predator	−2	−1	−1	−6

c) (* ⇒ Kindred)

	Background	Prey	Kindred	Predator
Background	−1	−2	1	−2
Prey	−2	−3	0	−3
Kindred	1	0	3	0
Predator	−2	−3	0	−3

d) (* ⇒ Background)

	-
Background	1
Prey	−1
Kindred	−1
Predator	−1

2.5 Evolutionary operations

Organisms are selected to compose next generation by the roulette selection based on their scores. If there is an organism with a negative score, all the scores are added a constant so as to make the minimum score to be zero before performing the roulette selection. Then, following four types of mutation are preformed on their production rules of the selected individuals (Fig. 6).

Duplication A rule is duplicated and inserted into the rules as the immediately previous rule of the rule according to a probability, P_{dup}.

Deletion A rule is deleted according to a probability, P_{del}.

Modification A symbol is randomly selected and changed to be another symbol randomly according to a probability, P_{mod}.

Swap A rule is exchanged its location in the rule sets with another randomly selected rule according to a probability, P_{swp}.

- Duplication (P_{dup})

$$\begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, s_1, s_4) \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, G) \end{array} \Rightarrow \begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, s_1, s_4) \\ \underline{2: s_1 \rightarrow (s_1, s_2, s_1, s_4)} \\ 3: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, G) \end{array}$$

- Deletion (P_{del})

$$\begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, s_1, s_4) \\ \underline{2: s_3 \rightarrow (s_3, s_2, s_2, s_1)} \\ 3: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, G) \end{array} \Rightarrow \begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, s_1, s_4) \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, G) \end{array}$$

- Modification (P_{mod})

$$\begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, \underline{s_1}, s_4) \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, \underline{G}) \end{array} \Rightarrow \begin{array}{l} 1: s_1 \rightarrow (s_1, s_2, \underline{s_2}, s_4) \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ (s_1, s_2, s_3) \rightarrow (R, B, \underline{R}) \end{array}$$

- Swap (P_{swp})

$$\begin{array}{l} \underline{1: s_1 \rightarrow (s_1, s_2, s_1, s_4)} \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ \underline{3: s_3 \rightarrow (s_3, s_2, s_2, s_1)} \\ \text{p}(s_1, s_2, s_3) \rightarrow (R, B, G) \end{array} \Rightarrow \begin{array}{l} \underline{1: s_3 \rightarrow (s_3, s_2, s_2, s_1)} \\ 2: s_2 \rightarrow (s_1, s_1, s_2, s_3) \\ \underline{3: s_1 \rightarrow (s_1, s_2, s_1, s_4)} \\ (s_1, s_2, s_3) \rightarrow (R, B, G) \end{array}$$

Fig. 6 Examples of mutation.

3. Experiments

We have conducted some experiments according to the description of the model in the previous sections (Fig. 7). The number of species was two – prey and predator, and the number of the each organism was

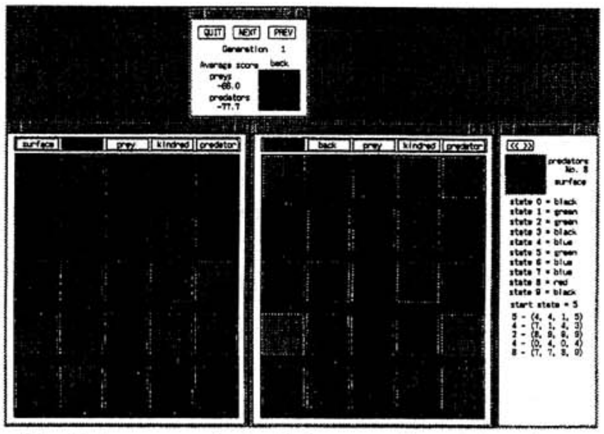

Fig. 7 A screen shot of the experimental system.

25. The symbols and colors were 10 and 4, respectively. The depth d in the grammars was 6, and $P_{dup} = P_{del} = P_{mod} = P_{swp} = 0.01$. Table 1 was used for rewarding. The background was all black.

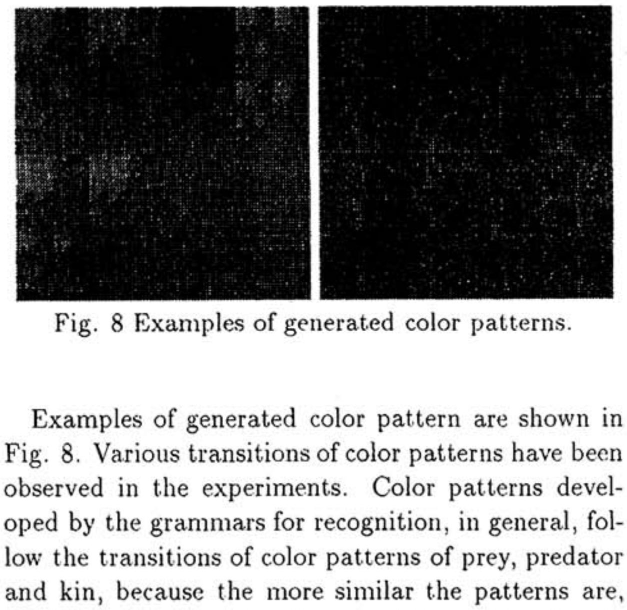

Fig. 8 Examples of generated color patterns.

Examples of generated color pattern are shown in Fig. 8. Various transitions of color patterns have been observed in the experiments. Color patterns developed by the grammars for recognition, in general, follow the transitions of color patterns of prey, predator and kin, because the more similar the patterns are, the higher the organism's score. The epidermis patterns of organisms as prey have a tendency to become misleading patterns, for example, which are similar to the patterns for predators in the recognition systems of the predators. At the same time, the epidermis patterns of the organisms as predator also have a tendency to become misleading pattern, for example, which are similar to the patterns for prey in the recognition systems of the prey. Coevolution requires a specific evolutionary response by both species: specific new defences by the prey must be continually counteracted by specific new defence-breakers in the predator, and vice versa.

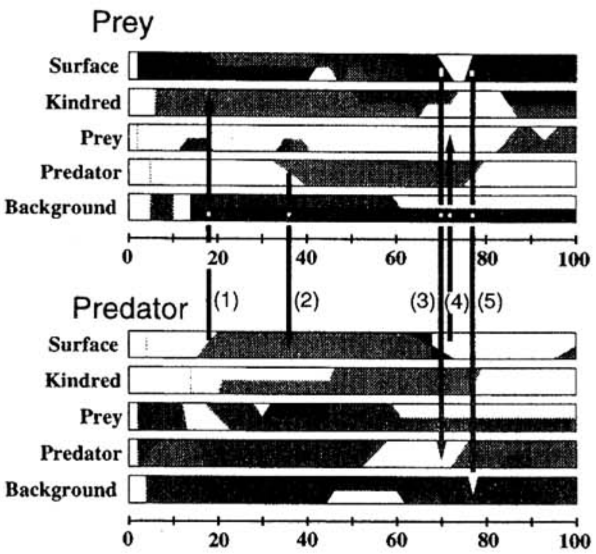

Fig. 9 An example of transitions of color patterns.

Typical change of color patterns in some experiment is shown in Fig. 9. The color pattern which represents each generation is expressed by some level of gray in this figure. For example, at the 70th generation, the prey organisms have changed their epidermis patterns into the similar patterns to the patterns for predators in recognition systems of the predators (Fig. 9 (3)), which can make the predators recognize the prey as their predators. At the 20th generation, the predator organisms have changed their epidermis patterns into the similar patterns to the patterns for kindred in recognition systems of the prey (Fig. 9 (1)). At the 35th generation, the prey organisms have changed their patterns for predators in recognition systems into the similar pattern of the epidermis patterns of the typical predators (Fig. 9 (2)), which can make the predators recognize the predators.

4. Towards Evolvable Exterior

A simple model for color pattern generation based on the evolutionary dynamics has been constructed as a first step, and the results of the experiments have been presented simply as illustration of the core of the ideas in the previous sections. There are many ways to obtain more complex and beautiful color patterns, as follows.

(1) background pattern setting (current model adopts all black)

(2) increase of colors (current model uses only 4)

(3) increase of the species and the food-web links

(4) modification of the algorithm of color pattern generation

(5) introduction of the other coevolution dynamics.

We have been extending the model and conducting some experiments to increase colors and obtain other types of color patterns. In the extended model, each organism has three grammars for developing color patterns on its epidermis , instead of one grammar in the original model. These three patterns correspond to red, green, blue, respectively, and the color mapping rules were replaced by brightness rules, by which 4 levels are assigned instead of 4 colors. Each color pattern on epidermis is generated by adding these RGB planes at each square patches. Therefore, color patterns can have 64 colors in this model. There is no modification in the process of pattern recognition, except that epidermis patterns are quantized as 4 gray levels and the patterns for recognition are interpreted to 4 gray levels (Fig. 10). We have been conducting some preliminary experiments based on this extended model. Fig. 11 shows the examples of generated color patterns. We have observed the similar evolutionary dynamics to the original model, and obtained more complex color patterns.

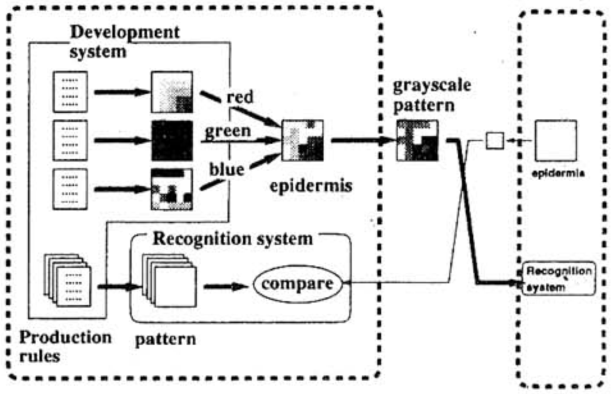

Fig. 10 Development system and recognition system in the extended model.

One of the ultimate goals of this approach towards embodiment of the concept of evolvable exterior is to realize dynamic transitions of color patterns on the surfaces (display devices) of the artifact-systems based on the interactions among surrounding entities, while it is our present goal to put these models into concrete shape as a design tool based on the results of the experiments. It will be necessary to address several is-

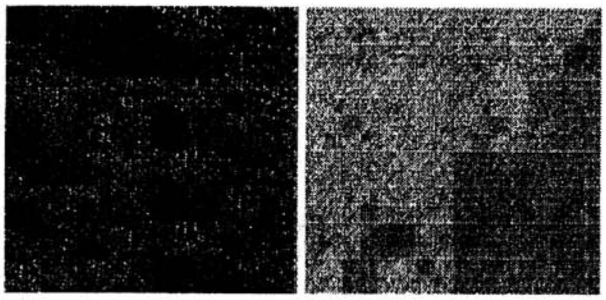

Fig. 11 Examples of generated color patterns.

sues towards embodiment of the concept of evolvable exterior:

1) Devices The ultimate systems based on the proposed models will require small computer systems equipped with the ultra-thin display devices and ultra-small camera devices on the surfaces of all the possible artifacts that surrounds us. Such situation will be distinct possibility, when the world at the cusp of the "post-information age"[6] comes.

2) Psychology What kinds of color patterns give us comfortable feeling? If it deeply depends on the internal states of our minds, what kind of human interface is adequate to input the internal states of minds? Various researches in broad areas must be considered to address this challenging issue.

3) Dynamics The current models adopt only the dynamics of predator-prey interactions as a driving force of color pattern evolution. Diversity of color patterns is sure to be created by introducing other evolutionary dynamics and interactions into the models.

5. Summary

This paper describes a model for the evolutionary systems to generate various color patterns dynamically by the generalized coevolution mechanism based on the interactions between predators and prey. We also discuss the feasibility of the evolution of color patterns on the surfaces of artifact-systems based on the encouraging results of the experiments.

If we keep our eyes on surrounding natural entities, and aim to create harmony in the world of natural entities and artifact-systems, the bottom up mechanism, that is called "emergence", must become essential in the artifact-systems, because nature itself has the mechanism for generation of emergent phenomena. Artificial life must surely be a prominent candidate for the methodology that can give reasonable evolutionary explanation of the mechanism for emergent phenomena, and can apply them to artifact-systems in not so distant future.

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