A Model for Coevolution

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Abstract

In the natural world, many kinds of animals and plants have been evolving mutually influenced. This study aims to investigate how the differentiation of species occurs through coevolution. We have constructed a model by computer simulation, which is compared to coevolution of bees and flowers. By the use of the model, the process of breading have been examined. The influence on correspondence between genotypic genes and phenotypic genes has been examined as well.

1 Introduction

For the evolution of creatures, mutual interaction is important. This is called coevolution. Competitive relation between gnus and lions, and cooperative relation between bees and flowers are good examples of coevolution. The aim of this research is to construct a model for coevolution and to investigate the mechanisms of differentiation of species through coevolution[1].

We start with introducing an example of coevolution, that is, the relation between hammer orchids and wasps. A hammer orchid has a sort of lure, which resembles a female wasp in its shape and pheromone (Fig. 1-a). A male wasp catches the dummy by mistake (Fig. 1-b). It tries to fly with the dummy and touches the pollen, because the flower is connected to the stem with a hinge (Fig. 1-c). It transfers pollen from flower to flower (Fig. 1-d). This is the example we focus on to construct a model for coevolution.

Every creature has genes (genotype) as biological information. Different genes do not necessarily describe different observable characteristics (phenotype). We introduce genotype and phenotype to our model. For simplicity of the argument, it is assumed that there are only two kinds of creatures in the world, one is "FLOWER" and the other is "BEE". First, our model

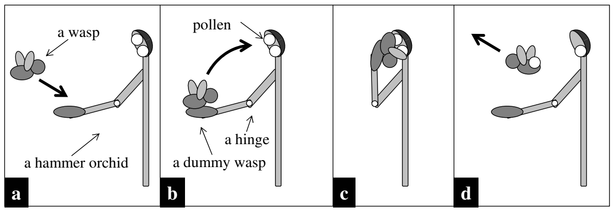


Figure 1: A hammer orchid and a wasp.

of bees and flowers is introduced. The characteristics of creatures are decided by the phenotype that is described by the genotype. In this model, a bee flies to a flower whose color is its favorite. If the shape of the bee fits to that of the flower, the bee can get pollen. It can also get nectar (that is, energy), if the nectar of the flower is its favorite one. After bees' gathering the nectar and transferring the pollen, the bees and the flowers bear their children. Probability of mating of a flower increases according to the number of times it received pollen. The number of mating of a bee is decided by the amount of the energy that it gathered. This is how we model the cooperative relation between bees and flowers. Secondly, we discuss the differentiation of species through coevolution and show that such differentiation occurs in our model. In addition, it is confirmed that differentiation of species is influenced by the relation between genotype and phenotype and by the condition of mating.

2 Model of Bees and Flowers

In this section, the detail of our model is described. The model consists of bees and flowers. Hereafter we denote BEE's and FLOWER's for those in the model. Since an accurate model is not necessary for our purpose, there is neither a queen bee nor the difference between a male and a female. BEE's and FLOWER's have genes. The genes have genotypic and phenotypic expression. The detail is described in section 2.1.

In section 2.2, the behavior of BEE's and FLOWER's are explained. There are two phases. One is pollinating phase, where BEE's fly to FLOWER's to get nectar and transfer pollen. The other is breeding phase, where BEE's and FLOWER's bear children. A sequence of a pollinating phase and a breeding phase is called a cycle.

2.1 Phenotype and Genotype

BEE's and FLOWER's have genotypic genes. The same observable characteristic does not necessarily correspond to the same genotypic gene. Sometimes, a few genotypic genes express the same characteristic. This characteristic expression is called phenotype. A BEE has three genotypic genes each of which is composed of 4 bits. Totally they are represented by 12 bits $x_1x_2x_3x_4|x_5x_6x_7x_8|x_9x_{10}x_{11}x_{12}$, and corresponding phenotypic genes are $X_1X_2X_3$. In the same manner, genotypic genes of a FLOWER are represented by $y_1y_2y_3y_4|y_5y_6y_7y_8|y_9y_{10}y_{11}y_{12}$, and phenotypic genes are $Y_1Y_2Y_3$. Y_1, Y_2, and Y_3 describe a color, shape, and nectar, respectively, where each of them takes a value out of A, B, and C. X_1, X_2, and X_3 are the BEE's favorite color, fitting shape, and favorite nectar, respectively. Each of them also takes a value out of A, B, and C. DNA and a characteristic in a real creature correspond to genotype and phenotype, respectively. In our model, we define the correspondence between genotype and phenotype, and investigate how coevolution happens through interactions. One example of such correspondence is shown in Fig. 2 as relation rule 1, and another in Fig. 3 as relation rule 2. Though in the model, both coding of genes and the relation rule are quite different between bees and flowers, the same coding and the same rule are applied to BEE's and FLOWER's. The essence of coevolution still exists in the model. In Fig. 2, each of the genotypic genes is assigned to a phenotypic gene at random. In Fig. 3, similar genotypic genes are assigned to the same phenotypic gene, that is, genes with zero and single 1's are assigned to phenotype A, with two 1 to B, and with three and four 1's to C. The lines indicate the relation between two genotypic genes where 1 bit is inverted.

Table 1 shows an example of relation between genotypic and phenotypic genes adopting relation rule 1 in Fig. 2. There are a BEE with ABA and a FLOWER with ABB. The BEE likes the color of the FLOWER and fits to it in the shape, and can take the pollen and the nectar, but the nectar is not nutrient for the BEE.

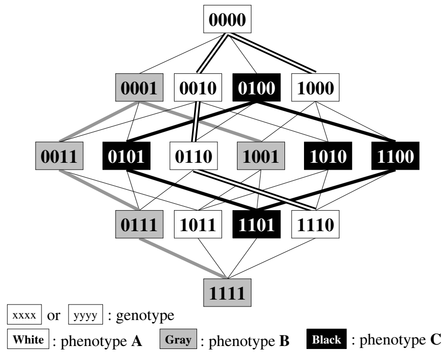


Figure 2: Relation between genotype and phenotype (relation rule 1).

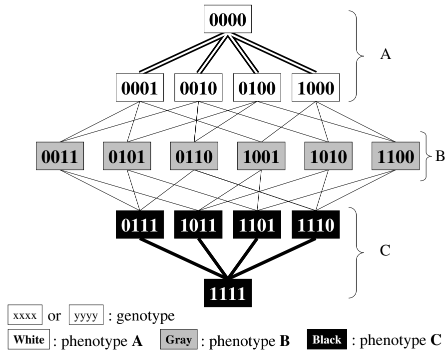


Figure 3: Another relation rule (relation rule 2).

It is assumed that creatures with the same phenotypic genes constitute one species.

2.2 Pollinating and Breeding Phase

The details of the behavior of BEE's and FLOWER's in pollinating phase and breeding phase are described as follows.

Pollinating phase The pollinating phase consists of 3 steps. Every BEE acts as step 1 $\sim$ 3.

Step 1 A BEE flies to a few FLOWER's (five FLOWER's for example) that have its favorite color and spends some energy. If the energy becomes zero, the BEE dies. The BEE finishes flying to any FLOWER, if there is no FLOWER with its favorite color.

Step 2 If the shape of the FLOWER fits to that of the BEE, it gives the FLOWER pollen which it has taken from another FLOWER and takes new pollen from the FLOWER. The BEE does nei-

	genotypic genes	phenotypic genes
BEE	0000 0001 0110	ABA
FLOWER	1000 1001 0001	ABB

Table 1: An example of genes of a BEE and a FLOWER in the case of relation rule 1.

ther give nor take pollen if it dose not fit to the FLOWER in the shape.

Step 3 Presume that BEE's can recognize whether the nectar is nutrient for it or not. If the nectar is nutrient, the BEE gathers the nectar (some energy), and the FLOWER looses a part of the nectar. Therefore, a BEE can not gather the nectar from the FLOWER which lost all the nectar. The nectar is recovered at the end of the cycle.

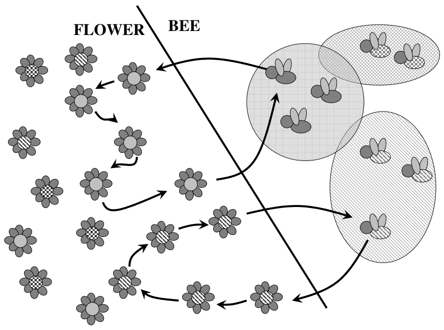


Figure 4: BEE's fly to FLOWER's.

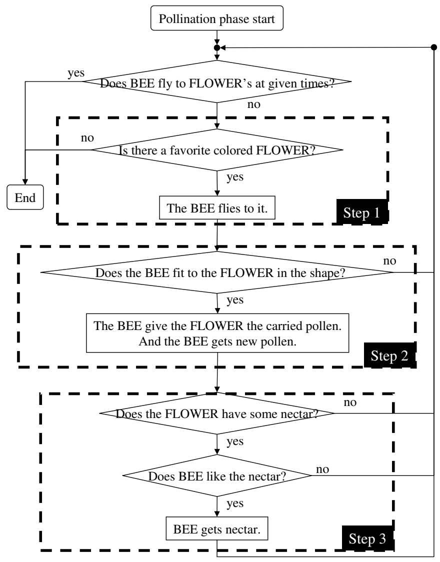


Figure 5: Flowchart of pollinating phase.

Figure 4 illustrates that BEE's fly to five FLOWER's with their favorite color one by one. And a flowchart of this phase is shown in Fig. 5.

The BEE in the breeding phase : A BEE can bear children in proportion to its energy. Whether two BEE's are able to mate or not, is not decided by phenotype but by genotype. First, two BEE's are chosen at random. Secondly, a similarity of their genotypic genes is examined. Finally, the BEE's bear a child through mating, if their genotypic genes are similar. Mutation can happen at this point. The similarity is evaluated by the Hamming distance between their genotypic genes. The maximum of the difference, where mating is possible, is defined as **MPD** (Maximum Permitted Difference). In other word, two BEE's can bear a new BEE, when different bits between their genotypic genes are less than MPD. This parameter is important in the following simulations. Mating is performed in every gene but not in every bit. In addition, the BEE's give certain energy to the child.

The FLOWER in the breeding phase : A FLOWER and the transferred pollen bear a new FLOWER as the BEE's. Maximum number of FLOWER's is limited. That is, randomly chosen FLOWER's bear new FLOWER's until the maximum number is reached.

In addition, BEE's and FLOWER's are given a lifetime. They die of the lifetime, after breeding phase.

3 Differentiation of Species though Coevolution

After the process described in the previous section, BEE's and FLOWER's with new genes appear. The creatures with the same phenotypic genes constitute a sub-species. Most of the sub-species can not survive because the population is small, but a few of them survive where the population increases to make new species. Fig. 6 shows an example of the differentiation of species through the coevolution. In initial condition, there are only two species, BEE's with AAA and FLOWER's with AAA. It is assumed that a new sub-species of FLOWER's with BAA appeared after some cycles. The sub-species survives by chance. If BEE's with BAA appear and increase after some cycles from the appearance of FLOWER's with BAA, BEE's with BAA and FLOWER's with BAA mutually cooperate with and survive. Also, the BEE's with BAB and the FLOWER's with BAB survive.

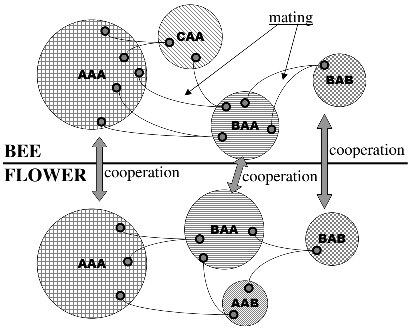


Figure 6: Differentiation of species though coevolution.

4 Simulation

The basic parameters are chosen as in Tab. 2. At the initial point, there are 10 BEE's and 10 FLOWER's. Their genotypic genes are 0000 0000 0000. Every BEE flies to 5 FLOWER's. First, a basic simulation is shown in section 4.1. As the result, it has been confirmed that differentiation of species occurs. Secondly, the influence of MPD on differentiation of species is analyzed in section 4.2. Finally, in section 4.3, another relation table is adopted.

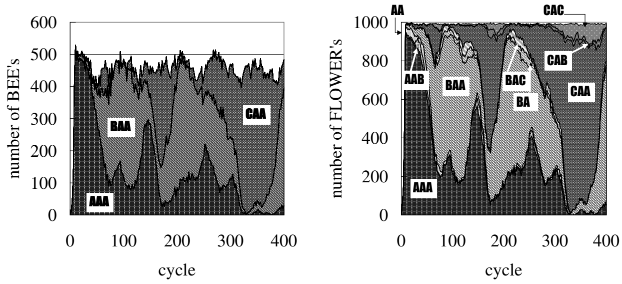
item	**value**
Initial energy of a BEE	5 [point]
Initial energy of a FLOWER	10 [point]
Energy that is necessary to fly to a FLOWER	1 [point]
Energy that a BEE gets from a FLOWER	2 [point]
Energy that a FLOWER gives to a BEE	2 [point]
Energy that two BEE's give to a new BEE	5 [point]
Lifetime	5 [cycle]

Table 2: Definition of basic parameters.

4.1 Basic Simulation

This simulation is performed with a relation rule in Fig. 2 and MPD = 4 [bit]. The results are shown in Fig. 7-a, b. These figures show time evolution of the population BEE's and FLOWER's of every species at every cycle. There are many species at the same time. It means that differentiation of species has occurred.

In addition, two interesting phenomena are observed. One is that two new species of BEE's with BAA and CAA, that have different favorite color from



a. BEE **b.** FLOWER

Figure 7: Time evolution of the population of every species at every cycle with relation rule 1 and MPD = 4.

the original one (AAA), have appeared. The BEE's with AAA can not gather enough nectar to mate, because the maximum number of FLOWER's and the amount of the nectar that a FLOWER generates are limited. If FLOWER's that has different color appear, the BEE's that like the color can gather more nectar than the BEE's of other species. Then, the new BEE's and the new FLOWER's increase. For this reason, increase and decrease of species are repeated. On the other hand, FLOWER's that have the same color and shape as the original one but have different nectar appear. The FLOWER's can survive, because they attract the BEE's and receive pollen. However, even if the FLOWER's increase, many BEE's that fly to them can not gather the nectar, because it is not their favorite one. The BEE's decrease, because the energy is not enough to bear children. It is considered that the model is stable at the condition that the number of the FLOWER is small.

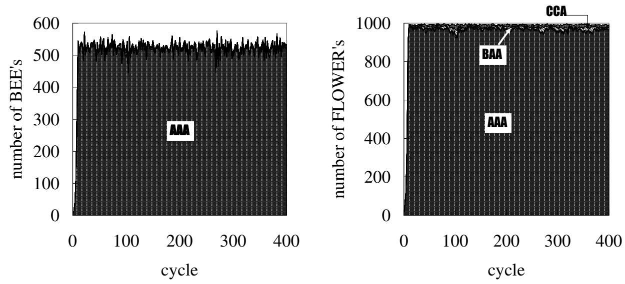
4.2 Influence on the MPD

First, the simulation has been performed in the case of MPD = 0. The results are illustrated in Fig. 8. It is confirmed that differentiation of species does not occur.

Next, the simulations under the condition of MPD = 2 and MPD = 3 have been tried to investigate how MPD influences the differentiation Fig. 9 and Fig. 10 show that different species is easier to occur, as MPD increases.

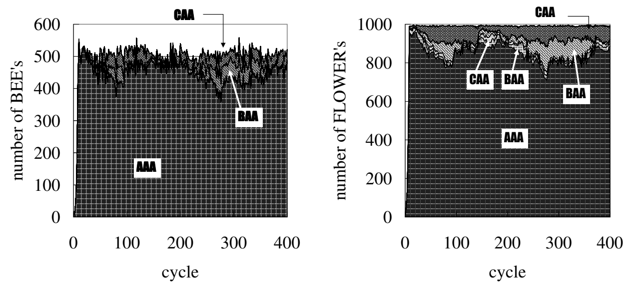
4.3 Influence of Relation between Genotype and Phenotype

Figure 11 shows the result when relation rule 2 in Fig. 3 is adopted. In this case, differentiation of species does not occur. The reason is considered as



a. BEE **b.** FLOWER

Figure 8: Time evolution of the population of every species at every cycle with relation rule 1 and MPD = 0, that is, their genotypic genes must be exactly the same in order to mate.



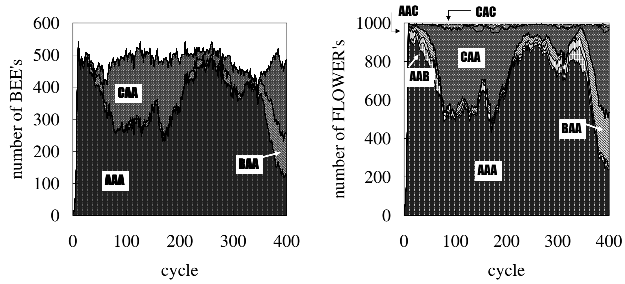
a. BEE **b.** FLOWER

Figure 9: Time evolution of the population of every species at every cycle with relation rule 1 and MPD = 2.

follows: when the genotypic genes have a close relation with phenotypic genes, two creatures belonging to different species can not mate with each other. Therefore the sub-species that appears from original one can not survive for a long time.

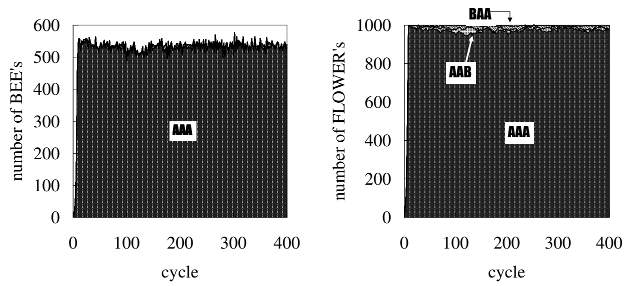
5 Conclusion

We constructed a model for coevolution of bees and flowers. Using the model, we confirmed that the differentiation of species occurs through coevolution. Influence of various parameters to the process of evolution is investigated. The differentiation of species is influenced by the relation between genotype and phenotype. It easily occurs when relation rule 1 (randomly constructed) is adopted. Next, it is easier to occur, as MPD (Maximum Permitted Difference) is larger. It has been found that lifetime of creatures, number of FLOWER's which a BEE flies to, getting and consuming energy, and maximum number of FLOWER's do not make much influence on the differentiation of



a. BEE **b.** FLOWER

Figure 10: Time evolution of the population of every species at every cycle with relation table 1 and MPD = 3



a. BEE **b.** FLOWER

Figure 11: Time evolution of the population of every species at every cycle with relation rule 2 and MPD = 4.

species.

To investigate the behavior of more complicated bio-systems composed of many kinds of animals and plants is one of our future works.

Reference

[1] K. Makino and K. Nakano, "The 66th National Convention of IPSJ," *Information Processing Society of Japan* ,Vol. 2, pp. 15-16, 2004.