MODELING CULTURAL EVOLUTION
CONTROLLED BY GROUP MUTATION AND SELECTION:
HOMAGE TO DARWIN, BALDWIN, AND RASHEVSKY

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SUMMARY

Darwin suggested an hierarchical approach to evolution and selection. Baldwin (1897,1902,1909) is probably the first to propose the important terms such as group selection, inter-group selection, social selection, imitative selection, and others. Three simple models of cultural evolution are presented. The first, which assumes group mutation alone, is an extension of what I call Rashevsky's hawk-dove evolutionary model. The second assumes group selection only. The third model integrates the first and second, i.e. group mutation and selection, models.

1. Introduction: The Tradition of Darwin to Baldwin

Darwin (1859, 1871) implicitly recognized the necessity of an hierarchical approach to the problems of evolution and selection (Ohta, 1982). He (Darwin, 1871) explicitly pointed out that group selection is important in cultural evolution of man.

After Darwin, the well-known psychologist, sociologist, and evolutionist Baldwin, in his two little-known books (Baldwin, 1897, 1909) and well-known book (Baldwin, 1902) at least to biologists, took a more explicit, multi-dimensional approach to evolution and selection. To my best knowledge, the Baldwin books are the first to classify various sorts of selection and to propose the new terms such as group selection, inter-group selection, social selection, personal selection, imitative selection, and others, in addition to the well-known term 'organic selection'. Of course he also acknowledged the importance of group selection for the evolution of humanities.

Most of later students, however, have neglected this great tradition of Darwin to Baldwin, and it seems to me that few mathematical studies have been done on group selection and/or mutation related to cultural evolution, irrespective of recent rapid developments of the mathematical theories of cultural evolution (e.g. Pulliam & Dunford, 1980; Cavalli-Sforza & Feldman, 1981; Fagen, 1981; Lumsden & Wilson, 1981). The only one which I could find relevant is the 1968 work of Rashevsky, the founder of mathematical history and of mathematical biosociology.

2. Cultural Evolution Controlled by Group Mutation: A Generalization of Rashevsky's Hawk-Dove Evolutionary Model

Nicolas Rashevsky (1899-1977), one of the greatest mathematical biologists in this century, is the true founder of modern theoretical biosociology (or sociobiology, behavioral ecology, or the like if you

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prefer), though regrettably his great contributions to this area (e.g. Rashevsky, 1947, 1951, 1968) have not in the least properly been recognized probably due to his high originality (Ohta, 1974, 1983). One could say that the situation is somewhat similar to that for Mendel.

Rashevsky in his very exciting book on mathematical history (Rashevsky, 1968) presented a simple model for the evolution of aggressiveness in man by imitative mass behavior. The model assumes random contacts between aggressive and peaceful groups, and so in our terms it is a model of cultural evolution controlled by cultural, group mutation which can occur through intergroup contacts.

Rashevsky (1968) did not use the symbolic terms 'hawk' and 'dove', and his model is conceptually very different from the well-known hawk-dove evolutionary game model which was proposed, later than Rashevsky, by J. S. Price, G. R. Price, and Maynard Smith (see Ohta, in press). From our viewpoint of biosociology or sociobiology, however, Rashevsky's (1968) model for the evolution of aggressiveness or peacefulness is a kind of hawk-dove evolutionary model.

The aim of this section is to show that what we call Rashevsky's hawk-dove evolutionary model could be extended to a general model for cultural evolution of any traits controlled by group mutation.

Let us consider two types of groups, T_1 and T_2 , in a population, and denote their frequencies by p_1 and p_2 , respectively ($p_1 + p_2 = 1$). Assume that cultural mutation in any group can occur if and only if the group comes into contact with an alternative type of group and that the mutation rate of T_1 and T_2 are μ_1 and μ_2 , respectively. Further assume that the intergroup contact is binary but not necessarily completely at random. Thus we introduce the coefficient of assortative contact A , where $0 \leq A < 1$. The case of complete assortment, $A = 1$, is of no interest for the present problem.

Then the frequency, p_1' , of T_1 after a unit time is written as

$$p_1' = p_1[(1-A)p_1 + A] + (1-\mu_1)p_1(1-A)p_2 + \mu_2(1-A)p_1,$$

and so we have the difference equation:

$$\Delta p_1 = (1-A)(\mu_2 - \mu_1)p_1(1-p_1).$$

The analysis of this equation easily leads us to the following result:

- 1) If $\mu_1 < \mu_2$, then $p_1 = 1$ is a globally stable equilibrium and hence T_1 will be ultimately fixed;
- 2) If $\mu_1 > \mu_2$, then $p_1 = 0$ is a globally stable equilibrium and hence T_2 will be ultimately fixed;
- 3) If $\mu_1 = \mu_2$, then any point of p_1 is a neutral equilibrium.

We can thus conclude that a more 'hard-headed' type of groups will be fixed and that this result is independent of the pattern of intergroup contacts, represented by the parameter A .

3. Cultural Evolution Controlled by Group Selection

Now consider a model of cultural evolution guided by group selection only. Denote the relative fitnesses of two types of groups, T_1 and T_2 , by $1+s$ and 1 , respectively, where $s > -1$. We have then easily

$$p_1' = \frac{(1+s)p_1}{1+sp_1}$$

or

$$\Delta p_1 = \frac{sp_1(1-p_1)}{1+sp_1},$$

and the following result is a truism:

- 1) If $s > 0$, then T_1 will be ultimately fixed;
- 2) If $s < 0$, then T_2 will be ultimately fixed;
- 3) If $s = 0$, then the system is in neutral equilibrium.

4. Cultural Evolution Controlled by the Joint Action of Group Mutation and Selection

Lastly we shall consider a model of cultural evolution controlled by the joint action of group mutation and group selection. This is a synthesis of the models in the preceding two sections. For this case, we have

$$p_1' = \frac{(1+s)p_1[1+\delta(1-A)(1-p_1)]}{1+sp_1[1+\delta(1-A)(1-p_1)]}$$

or

$$\Delta p_1 = \frac{p_1(1-p_1)[s+\delta(1-A)(1-p_1)]}{1+sp_1[1+\delta(1-A)(1-p_1)]},$$

where $\delta = \mu_2 - \mu_1$ ($|\delta| \leq 1$) and $0 \leq A \leq 1$. Note that the case $A=1$ might be of some meaning for this general model.

The analysis of the above equation leads us to the following result:

- 1) If $[A < 1, \delta > 0, s > 0]$, $[A < 1, \delta s < 0, 0 \leq \delta s(1-A) + s + \delta(1-A)]$, $[A < 1, \delta = 0, s > 0]$, $[A < 1, \delta > 0, s = 0]$, or $[A = 1, s > 0]$, then T_1 will be ultimately fixed;
- 2) If $[A < 1, \delta < 0, s < 0]$, $[A < 1, \delta s < 0, s + \delta(1-A) \leq 0]$, $[A < 1, \delta = 0, s < 0]$, $[A < 1, \delta < 0, s = 0]$, or $[A = 1, s < 0]$, then T_2 will be ultimately fixed;
- 3) If $A < 1$, $\delta s < 0$, and $0 < s + \delta(1-A) < -\delta s(1-A)$, then there exists an unstable, internal equilibrium point,

$$p_1 = 1 + \frac{s + \delta(1-A)}{\delta s(1-A)}.$$

Thus, if the initial value of p_1 is less or greater than this threshold value, then T_2 or T_1 will be fixed, respectively;

- 4) If $[A < 1, \delta = s = 0]$ or $[A = 1, s = 0]$, then any point of p_1 is a neutral equilibrium.

Fig. 1 depicts on the (δ, s) parameter space all the possible ultimate states of the system for $A < 1$. It is to be noted that there exists no internal, stable equilibrium so that stable polymorphism cannot evolve for any case.

Needless to say, our models in the present paper might be too simple to apply to real situations. It is expected that in the future more elaborate models will be developed to more faithfully understand the mechanisms of cultural evolution.

We note finally that our cultural evolution models of group mutation/selection can be directly translated into those of individual mutation/selection (Ohta, in press).

Fig. 1.
Cultural evolution by means
of group mutation and sele-
ction.

F₁:T₁ fixation,
F₂:T₂ fixation,
U:Unstable, internal equili-
brium,
N:Neutral equilibrium.

The regions F₁, F₂, U, and N
correspond to cases 1), 2),
3), and 4), respectively.

For details see text.

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