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The effect of cultural interaction on cumulative cultural evolution

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HIGHLIGHTS

- Developed a new analytical model of cultural evolution.
- Studied what factors would affect cultural evolutionary speed in one population.
- Also investigated the effect of cultural interaction on cultural evolution.
- Cultural interaction sometimes accelerates cultural evolution.
- The analytical method is confirmed by individual-based simulations.

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ABSTRACT

Cultural transmission and cultural evolution are important for animals, especially for humans. I developed a new analytical model of cultural evolution, in which each newborn learns cultural traits from multiple individuals (exemplars) in parental generation, individually explores around learned cultural traits, judges the utility of known cultural traits, and adopts a mature cultural trait. Cultural evolutionary speed increases when individuals explore a wider range of cultural traits, accurately judge the skill level of cultural traits (strong direct bias), do not strongly conform to the population mean, increase the exploration range according to the variety of socially learned cultural traits (condition dependent exploration), and make smaller errors in social learning. Number of exemplars, population size, similarity of cultural traits between exemplars, and one-to-many transmission have little effect on cultural evolutionary speed. I also investigated how cultural interaction between two populations with different mean skill levels affects their cultural evolution. A population sometimes increases in skill level more if it encounters a less skilled population than if it does not encounter anyone. A less skilled population sometimes exceeds a more skilled population in skill level by cultural interaction between both populations. The appropriateness of this analytical method is confirmed by individual-based simulations.

1. Introduction

The great success of our species is supported by highly developed cultures, which have evolved over time through repeated bouts of innovation, improvement, and social transmission. Recently, cultural evolution of nonhuman animals has also been reported using time series data (Allen et al., 2013; Van de Waal et al., 2013). As population genetics is necessary for investigating the evolution of genetic traits, theoretical research on cultural transmission is important for cultural evolution. While genetic traits are most often transmitted from parents to offspring, cultural traits are transmitted through social learning, which is a more complex process than heredity. Therefore, theoretical models different from population genetics are necessary for investigating cultural evolution.

Since the 1970s, many researchers have studied cultural evolution from a theoretical standpoint (Cavalli-Sforza and Feldman, 1973, 1981; Boyd and Richerson, 1985). Because cultural evolution encompasses many factors, previous theoretical research on cultural evolution covers various topics. The most well researched topic is the evolution of learning strategies that could promote and support cultural evolution. Many studies have focused on the effect of environmental stability (Boyd and Richerson, 1988; Rogers, 1988; Feldman et al., 1996; Henrich and Boyd, 1998; Enquist et al., 2007; Nakahashi, 2007, 2010, 2013a, 2013b; McElreath and Strimling, 2008) and spatial structure (Aoki and Nakahashi, 2008; Aoki, 2010; Rendell et al., 2010; Kobayashi and Wakano, 2012; Nakahashi et al., 2012) on the evolution of individual learning and various types of social learning. These studies discuss how culture coevolves with learning strategies by obtaining the frequency of adaptive cultural trait (or skill level) at

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equilibrium. Many researchers have also studied how culture (skill level) would evolve without considering the coevolution of learning strategies (Henrich, 2004; Powell et al., 2009; Kobayashi and Aoki, 2012). These studies discuss what factors accelerate cultural evolutionary speed under various conditions. In this paper, I focus on the latter issue.

Henrich (2004) has presented a simple analytical model to show that larger population size facilitates cumulative cultural evolution toward higher skill levels. Kobayashi and Aoki (2012) extended Henrich's model to show that a larger number of acquaintances and overlapping-generations also facilitate cultural evolution. In these studies, each newborn is assumed to learn a cultural trait from the most highly skilled individual in the population (Henrich, 2004), or among its acquaintances (Kobayashi and Aoki, 2012), but its mature skill level may disagree with that of the cultural parent because of inaccurate social learning and exploratory individual learning. The directly biased social learning rule of choosing the most skilled individual among candidates as the cultural parent is called the best-of-k (Aoki et al., 2011).

Although humans tend to learn from a successful individual (Henrich and Broesch, 2011; Mesoudi, 2011), the most successful individual does not always have the highest skill level in the real world. The success of individuals is determined by many factors, including a chance factor. In many cases the best behavior is unclear. In fact, meaningless cultural traits are sometimes transmitted by hitchhiking successful individuals (Mesoudi and O'Brien, 2008; Henrich and Broesch, 2011). Moreover, humans have other social learning biases (Laland, 2004). For example, we tend to avoid adopting extreme cultural traits (Boyd and Richerson, 1985). That is, the cultural parent is not always the most skilled individual among candidates. We have to investigate whether the results of Henrich (2004) and Kobayashi and Aoki (2012) hold even when more realistic social learning rules are assumed.

Another shortcoming of the previous studies on cultural evolution is that they assumed only one well-mixed population. In human history, cultural changes are often brought about by cultural interactions with other regional populations. For example, European art culture was strongly affected by ukiyo-e introduced from Japan. The direction of cultural evolution often varies in each region because of different environments, different initial conditions, different learning strategies, and random drift. Therefore, cultural difference between regions is sometimes very large and it is interesting to investigate how cultural interaction affects cultural evolution. Although the effect of structured population on cultural evolution has been theoretically studied (Lehmann et al., 2010; Kobayashi and Wakano, 2012), these studies have focused on skill level at equilibrium (or ESS). Human culture is evolving even now; therefore it may be better to investigate cultural evolutionary speed instead of the skill level of the equilibrium population.

Nakahashi (2013c) investigated how cultural interaction affects cultural evolutionary speed. However, since the paper was written for anthropologists, it mainly discussed how the model results could apply to the Paleolithic human cultural evolution, and did not show detailed mathematical derivations. Moreover, although many analytical results were obtained by using mathematical approximations, whether the approximations were appropriate was not confirmed by individual-based simulations. In this paper, I have shown the details of the mathematical derivations of Nakahashi (2013c) by including some additional cases, and confirm the analytical results by individual-based simulations. Instead of discussing the application of the model to human cultural evolution, I focused on mathematically interesting points of the model results. The models may apply to cultural evolution in other animals.

2. Model

2.1. Basic model

As in Henrich (2004) and Kobayashi and Aoki (2012), we assume that every mature individual has one cultural trait (skill) and that skill level is expressed as a real number. A newborn learns cultural traits from multiple individuals (exemplars) in the parental generation. The number of exemplars from which each newborn learns is k ($k \geq 2$). All newborns have the same number of exemplars.

Next, he/she explores around each socially learned cultural trait symmetrically with dispersion ϕ^2. That is, when he/she learns from an exemplar with skill level z_e, the skill level of "explored" cultural traits distributes with mean z_e and variance ϕ^2. Exploratory individual learning is the essential process for human cumulative culture (Henrich, 2004; Kobayashi and Aoki, 2012; Nakahashi, 2013a, 2013b). For example, when we learn how to broil meat from a cultural parent, we may basically follow his/her recipe but may add minor changes on broiling time and the amount of sauce to find the most delicious recipe for ourselves. Here, the mean skill level is assumed to be unchanged in this process, but the effect of its change is discussed in Section 2.6.

During exploratory individual learning, he/she compares and judges the utilities of explored cultural traits according to the following criterion to adopt his/her mature cultural trait. An experimental study showed that humans add minor changes in cultural traits and check their utilities to find the best cultural trait through an individual learning process (Mesoudi and O'Brien, 2008). We consider weak directional selection (preference) so that cultural traits of higher skill level have slightly larger utility. The relative probability that he/she adopts a cultural trait of level z is assumed to be a linear function of the utility of cultural trait,

$$w(z) = 1 + az \tag{1}$$

where a is small. That is, the exemplar with the highest skill level is not always chosen as a cultural parent, but the exemplar with higher skill level is more likely to be chosen. Larger a implies that each newborn can accurately judge (or strongly rely on) the skill level of cultural traits (strong direct bias). Note that every function can be approximated as this linear function provided selection is weak. All individuals are assumed to have the same criterion (preference).

Then, as shown in Appendix A, the expected skill level of the mature cultural trait of individual i is

$$E(z_i') = \bar{z}_i + \frac{s_i^2 + \phi^2}{1/a + \bar{z}_i}, \tag{2}$$

where $\bar{z}_i$ and s_i^2 are the mean and variance of skill level in his/her exemplars, respectively, which are assumed to be uncorrelated. Assuming that exemplars are randomly chosen from the parental generation, we have $E(\bar{z}_i) = \bar{z}$ and $E(s_i^2) = \sigma^2\ (k-1)/k$, where $\bar{z}$ and σ^2 are the population mean and variance of skill level in the parental generation respectively. As shown in Appendix B, the expected population mean in the offspring generation becomes

$$E(\bar{z}') = \bar{z} + \frac{\sigma^2(k-1)/k + \phi^2}{1/a + \bar{z}} \tag{3}$$

provided the selection is weak ($a\sigma \ll 1$). Therefore the expected generational change of mean skill level in the population is

$$\Delta\bar{z} = E(\bar{z}') - \bar{z} = \frac{\sigma^2(k-1)/k + \phi^2}{1/a + \bar{z}}, \tag{4}$$

which is defined as cultural evolutionary speed. This equation implies that the population mean and variance of skill level in the parental generation affect cultural evolutionary speed.