The Effects of Individual and Social Learning on the Evolution of Cognitive and Communicative Aspects of Language Abilities

Hiroto Yonenoh[1], Reiji Suzuki[1] and Takaya Arita[1]

[1]Graduate School of Informatics, Nagoya University, Japan
yoneoh.hiroto@a.mbox.nagoya-u.ac.jp

Introduction

Recently, it is recognized that human linguistic abilities and human language are likely to have been shaped by their co-evolutionary processes, in other words, the interplaying process of the biological evolution of the language faculty and the cultural evolution of language (Smith, 2018).

In a general context of co-evolution of biological and cultural processes, including that of language (Christiansen and Kirby, 2003), effects of individual and social learning have been regarded as important factors. Higashi et al. (2018) constructed a computational model of evolution on a rugged fitness landscape which has many local optima, assuming the evolution of a complex and adaptive ability composed of mutually interacting traits. They showed that individual learning and social learning could work complementarily in the course of adaptive evolution on the rugged fitness landscape. That is, individual learning can find new adaptive phenotypes thanks to the diversity of genetic expressions created by social learning. Social learning also can keep a new adaptive phenotype found by individual learning in the population. We consider the human language faculty as one of such abilities at least in part because it is composed of various sub-faculty traits of language (e.g., brain structures, vocal organs). There are thought to be two sorts of primary abilities of human language (Harman, 1975). One is a cognitive ability or capacity of thoughts (e.g., building language hierarchy). The other is a communicative ability (e.g., intention sharing). However, they only assumed mutual interactions among traits within an individual, which could be regarded as the traits related to the cognitive ability of language. Thus, in order to deal with the evolution of communication ability, the existence of a communication partner and inter-individual interactions of their traits must be assumed.

The purpose of this study is to clarify how cognitive and communicative abilities of language can evolve in terms of the co-evolution of linguistic abilities, based on social and individual learning. For this purpose, we extended the model of Higashi et al. (2018) by incorporating inter-individual interactions among traits into it.

Model

We constructed an extended version of Higashi et al. (2018)'s model. We assume a population of $N/2$ parent and $N/2$ child individuals, each has M traits $t_i \in [1, M]$ (i=0, 1, …, M-1) represented as positive integers. These traits are assumed to be related to sub-faculty traits of language. Each gene $g_i \in [1, M]$ in a M-length chromosome represents the initial (innate)

value of the corresponding trait t_i. Each individual has another M-length chromosome, each of which is a boolean value and decides whether the corresponding trait is plastic (learnable) or not. These settings are same as Higashi et al. (2018).

In each generation, $N/2$ pairs of individuals were randomly formed without duplication, and there are L steps of within-pair interactions in parallel. We assume a basic assumption on the contribution of trait sets to the fitness: a fitness contribution x emerges if there are equal or more than x traits whose value is x among the trait set of the focal individual. This represents that the more adaptive linguistic ability is based on the larger number of sub-faculty traits. Then, we define the co-creative fitness $FITNESS$ as the product of the following two types of fitness: $FITNESS=COG \times COM$. COG (cognitive fitness) of an individual i is the highest fitness contribution calculated from her trait set $\{t_i\}$ using the assumption above. COG is the fitness function used in Higashi et al. (2018). COM (communicative fitness) is the total fitness contribution calculated from the set $\{t_i, t_j\}$ of the trait set of the focal individual $\{t_i\}$ and that $\{t_j\}$ of her partner j in her pair. We adopted the total fitness contribution for COM to represent that various communication processes based on different sub-faculty traits can bring about different types of fitness contribution. The fitness landscape becomes dynamic due to the introduction of COM.

Each individual also has a social learning rate s, as a genetic value. At each step, each individual chooses social learning with the probability s or chooses individual learning with the probability 1-s. When choosing individual learning, an individual creates a slightly modified trait set from her innate trait set $\{g_i\}$ by adding a random value $\{-1, 0, 1\}$ to the value of g_i of each plastic trait. When choosing social learning, the focal individual tries to imitate the traits of the best individual in the previous step. The process makes each plastic trait closer to the corresponding trait of the selected individual, by adding -1 or $+1$ to g_i. The focal individual adopts the new trait set if its $FITNESS$ is higher than the one

Figure 1. The average fitness during the last 1,500 generations in the three learning conditions. The values were the average over 20 trials. The red arrow represents that a value on the start point is significantly lower than a value on the end point by Ryan's method with Wilcoxon signed-rank test (α=0.05).

in the previous step, assuming that her partner has the trait set in the previous step, otherwise keeps the previous one for fitness calculation. At the end of the generation, all the parent individuals die and the child individuals become parent individuals. $N/2$ new child individuals are created by using a roulette wheel selection from the new parent individuals based on the average co-creative fitness (*FITNESS*) over time steps, single-point crossover, and mutation.

Results and discussion

We conducted experiments with the parameter settings: N=1000, M=10, L=50 for 15,000 generation. We focused on the three learning conditions: "No learning condition", where the fitness of an individual is calculated with only the initial traits g_i; "Individual learning condition", where an individual performs individual learning only (s=0.0); and "Both learning condition", an individual can choose either individual or social learning according to her own social learning probability s.

Figure 1 shows the average fitness during the last 1,500 generations in the three learning conditions. Each of the lifetime fitness (right) means the average fitness values of *COG*, *COM* and *FITNESS*, respectively, and the innate fitness (left) is the fitness value calculated using the genetically determined trait values $\{g_i\}$. We see that each of the three fitness on Both learning condition was higher than the corresponding ones on No learning condition and Individual learning condition. In other words, mutual interactions between both individual and social learning facilitated the adaptive evolution of cognitive and communicative abilities of language. By contrast, if we focus on the innate fitness, there were significant differences in their evolutionary process between Individual learning and Both learning conditions. Each of the three innate fitness on Individual learning condition was higher than the corresponding one on No learning condition. In other words, individual learning facilitated the adaptive evolution of innate fitness. Our additional analysis showed that this result can be explained by the Baldwin effect (Baldwin, 1896) or genetic assimilation (Waddington, 1953) as the component of the Baldwin effect, which is expected to be due to the implicit cost of learning. However, each of the three innate fitness on Both learning condition was lower than the corresponding one on Individual condition, showing that the social learning process retarded the genetic acquisition of adaptive traits.

Figure 2 shows the rough trajectory of the population on the 3 fitness landscapes in a trial. On the top panel, we see that the both fitness gradually increased but there were several peaks of the fitness landscape, preventing the increase in the fitness. In addition, the difference between the lifetime and innate fitness tended to be large, implying that the learning process was getting more important to keep the high adaptivity. From the comparison between the middle and the bottom panels, we can see that the difference in the communicative fitness between the lifetime and innate fitness tended to be large and variable while the one in the cognitive fitness was small and steady. This means that it is more difficult for genetic assimilation to occur on communicative fitness than on cognitive fitness. This might be because
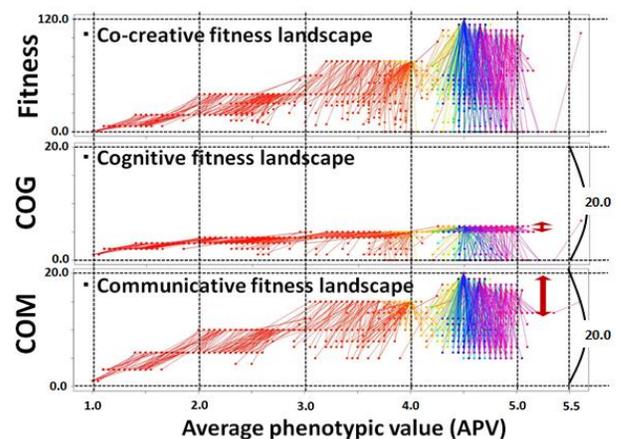

Figure 2. The rough trajectory of the population on the 3 fitness landscapes in a trial of Both learning condition. Each point represents the fitness value (y-axis) of the best individual in terms of co-creative fitness and her average trait value (x-axis). The innate and lifetime fitness of each individual were connected. The color gradation represents the generation (red->orange->yellow->blue->purple).

dynamic changes in the traits of her partner prevent an individual from genetically acquiring the high communicative ability while the innate cognitive ability tended to evolve stably because it is determined by her own traits.

Conclusion

We constructed an extended version of Higashi et al. (2018)'s model to clarify how cognitive and communicative abilities of language can evolve, based on social and individual learning. We found that roles of individual and social learning can work complementarily. It is also implied that the stable evolutionary process of cognitive abilities is based on repeated occurrences of the Baldwin effect and dynamic and less assimilated evolution of communicative traits can work together, contributing to the evolution of cognitive and communicative aspects of language abilities.

Acknowledgements

References

Baldwin, J. M. (1896). A new factor in evolution. *The American Naturalist*, 30 (354): 441-451.

Christiansen, M. H., and Kirby, S. (2003). Language evolution: consensus and controversies. *Trends in cognitive sciences*, 7 (7): 300-307.

Harman, G. (1975), Language, thought, and communication. *In: K. Gunderson (ed), Minnesota Studies in the Philosophy of Science*, 7: 270-298.

Higashi, M., Suzuki, R. and Arita, T. (2018), The Role of Social Learning in the Evolution on a Rugged Fitness Landscape. *Frontiers in Physics*, 6 (88).

Smith, K. (2018), How culture and biology interact to shape language and the language faculty. *Topics in Cognitive Sciences*, DOI: 10.1111/tops.12377.

Waddington, C. H. (1953). Genetic assimilation of an acquired character, *Evolution*, 7: 118-126.