RECURSIVE OPERATION ABILITY MAY EVOLVE FOR CREATIVITY

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One of the interesting features of human language is hierarchical structures of sentences, which can be formed by recursive applications of a simple combination operation. While the hierarchical structural has rarely been observed in the communication of other animals, similar recursive operations were observed in object manipulations by a chimpanzee (Matsuzawa, 1986) and human infants (Greenfield, 1972). Generally, manipulation of recursive objects is found in human behavior and this is supposed as a precursor of the recursiveness of language (Maynard Smith & Szathmáry, 1995; Fujita, 2009).

Based on this supposition, we considered the plausible adaptability of recursive operation as the important function of cognitive and linguistic ability using evolutionary simulations of object manipulation (Toya & Hashimoto, 2015). An agent performing object manipulation was modeled using automaton with a stack. The agents' aim was to create tools by combining objects. Our purpose was to identify environments (fitness functions) that promoted the evolution of recursive operation. We found that the recursive operation could evolve under two types of fitness functions: the adaptive behaviors were to make a specific tool with a complicated structure and to make tools as diverse as possible. In the former environment, the recursive operation helped in successfully making the target tool through multiple ways of production. The more complicated was the target tool, the larger were the ways of production and the success rate by recursive operations. In the latter, agents using recursive operation could earn fitness by making new tools at earlier generations than those agents who did not use recursive operation.

In this paper, we considered the effect of competition for resources. Assuming one to one correspondence between tools and their functions to obtain resources, for simplicity, we introduced the fitness function to include the competition among agents. The fitness of i th agent at generation t is given by the below equation:

$$F^i(t) = \sum_{\text{all } x} \frac{n_x^i(t)}{\left\{\sum_j n_x^j(t)\right\}^\alpha}, \tag{1}$$

where x is a tool, $n_x^i(t)$ is the number of the tool x that the ith agent makes at the generation t, and α is a parameter to control the strength of competition. Under this fitness function, while agents can earn fitness by making any tools, the contributions from each tool decreases according to the number of tools made by all agents (including the agent itself) at the same generation.

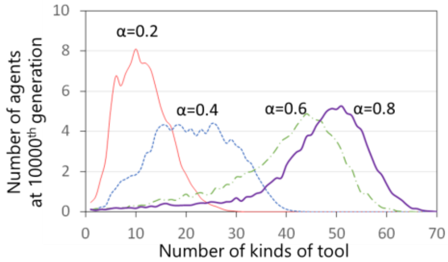

Figure 1. Effect of competition for resource.

In our simulations, the agent population using recursive operation increased when the competition was intensified. The number of agents making various tools evolved with larger α (Fig. 1). The environment with strong resource competitions promoted the evolution to generalists, namely, making a variety of tools, not a few specific ones.

From the previous results, we can say that the functions of recursive operation are to diversify the making methods and the products. The present results indicate that the recursive operation contributes to the invention of novel products and the evolution of generalists. Thus, it is suggested that the ability of recursive operation has evolved due to its creative power in a severe environment.

The creativity of recursive object manipulation is reflected on stone tools. As per the archeological evidence, the complex stone tools appeared in 280 Kyr is made by the recursive operation (Moore, 2010). Various stone tools in correspondence with the purposes appeared in 250-200 Kyr (Foley & Lahr, 1997; Lewin & Foley, 2004). We believe that the creative power of recursive manipulation was handed to the productivity by syntax, and increased cultural diversity of humankind. This speculation is supported by neuroscientific findings that suggest Broca's area to be involved in serial object manipulation (Grossman, 1980), hierarchical behavioral plans (Fazio et al., 2009), and processing musical sequences (Chen et al., 2008; Patel, 2003).

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