Title	
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Citation	
Issue Date	2019-03
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/15782
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Description	Supervisor: , ,

Abstract

Human language has a hierarchical structure that does not appear on expression. In theoretical linguistics, this feature is produced by recursive application of the operation combining two lexical items, i.e., recursive combination (RC). The purpose of this thesis is to construct a reasonable scenario of how RC emerged and evolved. In this thesis, based on the knowledge of linguistics, animal behavior, cognitive science, neuroscience, and the existing hypothesis that the ability of RC in object manipulation was a precursor of RC in syntax, I made a new hypothesis that ability of representation operation gained the capability of RC through the object manipulation.

Under this hypothesis, I made a simulation to identify the environmental conditions under which the ability of RC of object evolves. Specifically, I made an agent that produced tools by combining objects, and I simulated evolution under several ecologically reasonable fitness functions using genetic algorithms. Regardless of whether RC is used or not, the types of tools that agents can make are the same. However, agents that use RC uses short-term memory, which increases operating costs. In environments where it is necessary to raise the production success rate by diversifying the production method of the production and environments that need to raise the invention probability of new products due to diversification of the production themselves, RC evolved beyond the cost barriers. It was also confirmed that the environment in which RC is adaptive occurs due to intense competition for resource acquisition.

Next, I made a simulation to clarify what kind of adaptive significance RC of representation evolved. I conducted a simulation where agents' behavior of combinatorial operation is optimized according to a reward function by Q-learning and genetic algorithm. There are two types of agent in this simulation. One is an agent learns the relation between input state and output state. Another one is an agent update the value of adaptive behavior without action by using the result of learning, that is, the agent performs thinking experiment by combining representations of action. To explore ecological condition for the evolution of RC from actions to action representations, I simulated the evolution and learning of non-RC and RC as tool-making behavior under four conditions: if a fitness function for evolution changes according to tools made in previous generation; and if a reward function for learning changes according to tools made by oneself. I found that RC emerged only when reward changed and fitness did not. It suggests that RC in action representation evolve in an environment where making novel tools during one generation is rewarded.

In the discussion part, I suggested that the RC evolved as a heuristics that can obtain a reasonable solution in searching for a vast space in each cognitive domain including syntax.

Keywords: Recursive Combination, Evolution of Language, Grammar of Action, Hierarchical Structure, Constructive Approach