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Study on evolution of syntactic ability

-- The 'precursor' volume:

Evolutionary simulation of recursive object manipulation

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Although both animal calls and human languages use one-dimensional sound signals in communication, a remarkable feature of human language is that words are organized recursively and hierarchically into sentences. In theoretical linguistics, the hierarchical formation of language expression is explained in terms of the ability of a syntactic operation called "Merge". Merge is a set-formation operation that combines two lexical items into a set. Humans can create diverse and complex sentences by the recursive application of this operation (recursive Merge). It is thought that the ability of recursive Merge is unique to humans. To understand the origin and evolution of language, we must answer following questions. What was the evolutionary process of this ability? What was the adaptability of this ability, if the process was adaptive evolution? These questions are fundamental problems in evolutionary linguistics.

The three hypotheses used to explain the evolution of a new function can be applied to the evolution of language ability. They are:

A) Adaptation by natural selection: Adaptability of language for communication and thinking prompted the gradual progressive language evolution.
B) Spandrel: Language ability was emergent as a by-product of increased brain capacity.
C) Preadaptation: Traits once having other functions have developed to include the function of language.

With hypothesis A, it is difficult to explain the fact that nonhuman social animals have not developed language. Hypothesis B cannot explain why a by-product of increased brain capacity is language ability. Consequently, to provide a consistent explanation for the evolution of language ability, it is appropriate to accept hypothesis C that presumes the existence of precursors of language ability.

What is an appropriate precursor of recursive syntactic ability? It can be assumed that the "sub-assembly strategy" in "action grammar" is a candidate for a precursor. Action grammar is a syntactic behavioral representation such as object manipulation by abstracting the details of behavior. Simplified and regularized expressions of behavior as syntactic structures permit the classification, comparison, and analysis of behaviors. Sequential behaviors are classified into three different strategies in the framework of action grammar: pairing, pot, and sub-assembly strategies.

- Pairing strategy: Basic manipulation. A single active object acts on a single static object, where the active object is the one being manipulated.
- Pot strategy: Repeated manipulation. Multiple active objects act on a single static object.
- Sub-assembly strategy: Recursive manipulation. Two objects are combined into a pair, which is then manipulated as a single unit in the combination.

Fujita proposed a hypothesis that sub-assembly strategy was a precursor of recursive syntactic ability based on specific evidences. There is a relationship from a neural basis between object manipulation and language ability as indicated in reports that demonstrated that Broca's aphasia interfered with serial object manipulation. It was found that a sub-assembly strategy, a recursive combination of objects, was observed only in human subjects in an experiment of combining cups by human infants and chimpanzees. This fact leads to a conjecture that there exists a unique cognitive human ability indicating recurrence in object manipulation.

We modeled agents performing object manipulation assuming tool making using automata with stacks. An agent has a hand to hold an object and a stack to temporarily store objects. There is a workbench where object combination occurs. An agent action is selected from the six types depending on the state of its hand, stack, and workbench. A state transition table defined for each agent determines what actions are possible in each state and state transitions after actions are performed. The purpose of the agent is to create tools that combine up to three objects using three types of objects.

We analyzed the evolvability and evolutionary processes of recursive manipulation using a genetic algorithm. The state transition table of automaton is encoded in genes. Typically, a genetic algorithm is used to search for (quasi-)optimal solutions according to a fitness function representing a combinatorial optimization problem. In this simulation, however, we intend to identify fitness functions whose solutions are a sub-assembly strategy. Therefore, the candidates for the fitness functions are defined by considering the ecological meaning of the sub-assembly strategy, i.e., the adaptive value and environment to adapt and the evolutionary processes and evolvability are examined by evolutionary simulations.

The purpose of this simulation is to clarify conditions for a biological evolution of sub-assembly strategy from pot strategy.

We determined that the sub-assembly strategy was more effective in making multiple types of tool than the pot strategy; however, not in making many tools and a specific complicated tool. In our simulation, when agents used the sub-assembly strategy, a common tool part, made by the pot strategy, was used as a component of the various tools. This result suggests that the appearance of the sub-assembly strategy requires an environment where using various tools (or methods) with a common part in the structure (or the making operation) is advantageous for survival and reproductive success. The following evolutionary process was identified in our simulation. Initially, agents evolved to appropriately use the pot strategy for tool making. Then, agents that used stacks to retain the common part of the tools appeared. Finally, the sub-assembly strategy that combines the part of the tool in the stack appeared and spread.

The sub-assembly strategy had greater difficulty appearing when agents had less available time for tool making and the manipulation cost was increased. The sub-assembly strategy is not common in animal behavior; rather it is only found in humans. We assume that this strategy is costly and not adaptive in most environments. Consequently, we must identify environmental conditions that promote the evolution of the sub-assembly strategy considering the existence of manipulation cost. Manual dexterity may be a key factor to performing significant object manipulations with decreased cost.

The pot strategy, that is, repeating behavior, is observed in both humans and apes. Hence, we presumed that repeating object manipulation appeared in the early period of human evolution. Based on the above discussion on our findings that sub-assembly strategy could evolved in an environment where time limitation and cost of tool making are not severe, we speculate that the possible evolutionary process of recursive operation occurred as follows. First, hands and fingers evolved to become dexterous during the repeated tool making process using the pot strategy. Dexterity contributed to decrease the cost of object manipulation and increase the chance of tool making by shortening the time to make each tool. Tools having common parts increased with the increasing number of tools made. Finally, the common parts became storable and then used for making further various tools, that is, the appearance of the sub-assembly strategy.

To consider the evolution of the precursor of language ability, we must introduce other physical and environmental constraints in addition to time to use tool making and manipulation cost. It is also necessary to design fitness functions that consider more specific and concrete ecological meanings based on knowledge and evidence in human evolution and archeology.