Combinatorial optimization and self-disciplined computing by amoeba-based neurocomputer

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Creating a biocomputer with its hardware incorporating biological materials, is it possible to implement some unique functions that are difficult for conventional digital computers to deal with? A living organism is a hierarchically-structured system in which a number of self-organization processes run simultaneously on its multiple levels with their characteristic spatiotemporal scales. Because a self-organization process at each level involves a certain kind of benefit optimization such as energy minimization and stability maximization, it would be sound to assume that an organism is a particular kind of concurrent computing system in which a number of computing processes to solve different benefit optimization problems run concurrently by sharing common computational resources such as the energy and substances. Despite a lack of predefined decision program, if these hierarchically-intervened optimization processes are capable of making a self-disciplined decision, for example, a decision to accept a loss in short-term benefits of its local part for the sake of long-term gains of its global body, the decision capability may be exploited for discovering some unprogrammed but reasonable optimization criteria when incorporated in a biocomputer.

With this expectation, we created a computing system incorporating an amoeboid unicellular organism, a true slime mold *Physarum polycephalum*, known to exhibit rich spatiotemporal oscillatory behavior and sophisticated computational capabilities. Introducing an optical feedback according to a recurrent neural network model, we lead the amoeba's photosensitive branches to expand or shrink within a network-type chamber in search of a solution to the traveling salesman problem (TSP).

Here we demonstrate our system's high optimization capability of solving four-city TSP. Our system reaches and stabilizes an optimal solution, as the amoeba having photoavoidance changes its shape in search for the most stable configuration allowing the amoeba to maximize its body area while minimizing the risk of being illuminated.

Intriguingly, the maintained stabilizing mode of the solution, however, spontaneously switches to the destabilizing mode without any explicit external perturbation. Contrary to the photoavoidance, the amoeba starts to destabilize the once-reached solution by spontaneously expanding its branch under illumination, and restarts the solution-searching process. Consequently, our system finds multiple solutions by repeatedly switching between the stabilizing and destabilizing modes.

As long as the amoeba maintains the photoavoidance and stabilizes the solution without changing its shape, the amoeba is stuck in a stalemated situation eliminating any possibility of nutrient acquisition. However, the amoeba spontaneously takes a risk of being illuminated locally and temporally to restart its shape change. It may be possible to view this spontaneous behavior as implying biological systems' capability of self-disciplined decision to put their resources available at present into risky investments to target resource acquisitions in the future.

We speculate that the spontaneous destabilization occurs due to the existence of chaotic dynamics capable of amplifying tiny fluctuations in a microscopic level to affect the unstable shape change in a macroscopic level. Indeed, applying several nonlinear time series analysis to the amoeba's oscillatory movements, we obtained results suggesting that an individual amoeba might be characterized as a set of coupled chaotic oscillators.

Additionally, we present a new technique that we call "autonomous meta-problem solving." In this approach, our system not only can solve a given problem but also can find new problems and then determine solutions in a self-disciplined manner, by exploiting the amoeba's unique searching ability and spontaneous behavior.