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Comment

Broken paradox of the heap
Comment on "Does being multi-headed make you better at solving problems? A survey of Physarum-based models and computations" by Chao Gao et al.

Yukio Pegio Gunji [a,*], Iori Tani [b], Tomohiro Shirakawa [c]

[a] *Department of Intermedia Art and Science, School of Fundamental Science and Engineering, Waseda University, 3-4-1 Ohkubo, Shinjuku, Tokyo 169-0072, Japan*
[b] *Department of Human System Interaction, Graduate School of Science and Technology, Kwansei Gakuin University, Gakuen 2-1, Sanda 669-1337, Japan*
[c] *Department of Computer Science, National Defense Academy, Hashirimizu 1-1-20, Yokosuka 239-8686, Japan*

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Gao et al. survey the recent trend of physarum inspired computing based on the morphology, taxis and feedback [1]. They especially classify collected models based on taxis into the models with bottom–up modeling techniques and the models with top–down ones. Top–down modeling technique can use a steady state domain of biochemical diffusion–reaction system in which one agent explores the multiple cores of biochemical substrates. Bottom–up modeling technique can use multi-agents which employs to an autonomously distributed system. Feedback based system focuses on learning and/or reinforcement.

Applications of physarum inspired computing are discussed in terms of network planning, route planning and maze solving, in each model based on the morphology, taxis and feedback. However, each model can be applied to various computing problems if some devices are added to each model. Some models are based on bottom–up techniques and other are based on top–down techniques. As Gao et al. finally mentioned, the essential problem is hybridization of top–down and bottom–up optimization in computing. They describe that most of physarum inspired models can be applied only to optimization problems that can be mapped onto a shortest path problem. In our sense those problems are simple problems of which macroscopic optimization is equivalent to microscopic optimization.

While Gao et al. technically describe our model, called CELL [2] and its extended model, VP-S [3], they do not pay attention to the dynamic inference between top–down (macroscopic-) and bottom–up (microscopic) mechanism implemented in our model. Although our models are automaton fashioned, they seem to be an agent-based model with macroscopic constraint. Since such dynamics is strongly related to the hybrid optimization in the final section in [1], we here show how dynamic inference between macroscopic and microscopic mechanisms are embedded in our model. The key idea in it is broken "paradox of the heap".

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* Corresponding author.
E-mail address: yukio@waseda.jp (Y.P. Gunji).

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Why both macroscopic and microscopic mechanisms are needed in natural computation? If an ideal adequate initial and boundary conditions are set, optimization under microscopic mechanism must be equivalent to one under macroscopic mechanism. In natural computation, however, one cannot control initial and/or boundary conditions completely, and that entails discrepancy between macroscopic and microscopic mechanisms. That is why one needs both macroscopic and microscopic mechanisms under indefinite open environments. Moreover, one needs dynamic relationship between macroscopic and microscopic mechanisms.

Discrepancy between macroscopic and microscopic views under indefinite open environment is simply demonstrated by the paradox of the heap. The heap is interpreted by two ways, microscopic and macroscopic views. In microscopic view, the heap consists of indefinitely large number of sand grains. In macroscopic view, the heap is just a massive body like a rock. If the number of sand grains is infinite, nothing happens. If the number of sand grains is indefinitely large but finite, the discrepancy appears. It can be assumed that the heap consists of sand grains due to the microscopic view, and that removing one grain from the heap still leads to the heap due to the macroscopic view. Because of indefinitely large but finite sand grains, iteration of removing a grain finally entails one grain which is nothing but the heap. That is a contradiction. Thus, the paradox of the heap can show discrepancy between microscopic and macroscopic views under indefinite open environments.

Our model, CELL and VP-S implement macroscopic and microscopic views of the heap. While massive body consisting of the cells (grains) represents macroscopic view, asynchronously randomly moving cells (indicating or counting cells) represents microscopic view. Like a contradiction in the paradox of the heap, massive body set in the initial condition is destroyed and scattered around, if the dynamic inference is not implemented. The inference between macroscopic and microscopic mechanism is implemented as the device by which moved cells cannot be moved again. This device implies a "small whole body" in a CELL itself, which represents ambiguity of macroscopic and microscopic view, because moved cells are identified as a unity as a rock. This device provides the mechanism to maintain a whole body, CELL, not being scattered around, while the CELL continuously modifies its morphology. In this sense, paradox of the heap is broken, and that cannot lead to a contradiction, but can entail dynamic behavior like physarum and/or amoeba.

The model can be applied to cognitive problem by simple extension [4]. As mentioned before, our model seems to be an agent based model, they can be extended to an asynchronously updated agent model, which can reveal ant colony [5] and/or soldier crab swarms [6–10] like human cognitive system. Asynchronous updating can constitute both traffic jamming and information transport jump in a swarm, which can mediate microscopic and macroscopic optimizations.

Fig. 1 shows how dynamic inference between microscopic and macroscopic mechanisms is generated in our model. Initially, the cellular automata fashioned rule with asynchronously updating is given under a specific initial and boundary condition, which seems to be just a bottom up mechanism. The seed of top down mechanism is embedded in the form of initial and boundary condition. As time development proceeds, mesoscopic small body appears in a macroscopic whole body. Cells in a macroscopic whole body, which is asynchronously moved provide a small whole body, and a generated small body like obstacle sometimes inhibits and sometimes accelerate free movement of cells. Generation of a small body is also constrained under a morphology of macroscopic whole body, and vice versa. In other words, through generation of mesoscopic small body, mesoscopic and macroscopic mechanisms are explicitly differentiated, and mesoscopic small body can mediate microscopic and macroscopic mechanisms.

As mentioned before, macroscopic optimization is not equivalent to microscopic one under indefinite open environments. The hybrid optimization is proposed in various ways. In the final section of [1], the hybrid optimization of macroscopic and microscopic mechanisms is implemented as the linear coupling of two mechanisms in a differential equation. By contrast, we think that requirement of hybrid optimization is inevitable in natural computing (i.e. computing under indefinite open condition) and can be implemented in more natural ways. The idea of broken paradox of the heap can be a hint to construct the natural and dynamic interface between microscopic and macroscopic mechanism.

Under a complex potential consisting of multiple peaks, microscopic strategy to climb a peak is trapped into one of local optimal peaks and it cannot reach the global optimal peak which is suggested by macroscopic mechanism. Discrepancy between microscopic and macroscopic views are negotiated by some devices, classically by simulated annealing [11] and recently by reservoir computing [12] and inverse Bayesian inference [13].

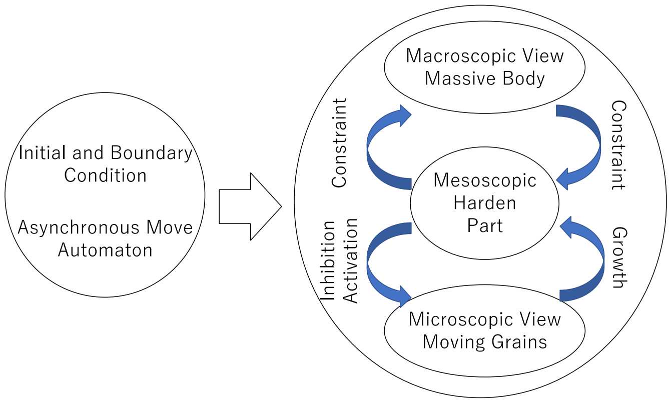

Fig. 1. Differentiation of microscopic and macroscopic views mediated by mesoscopic layer. Hybridization is autonomously generated.

Reservoir computing originally implement the material and/or morphological computing [14]. Reservoir such as water bucket could mediate microscopic input with macroscopic optimization when input is repeated by resonance and is mixed with noise. In this sense, Bio-material computing is also typical material computing [15].

In [13], Bayesian inference itself is regarded as microscopic strategy to the optimal solution and the negotiation between microscopic and macroscopic strategy is implemented to introduce inverse Bayesian inference. Strictly speaking dynamic negotiation between microscopic decision making and macroscopic given condition is implemented as a pair of Bayesian and inverse Bayesian inference. We extend this idea, and define Bayesian inference by replacing the probability of hypothesis with the conditional probability of hypothesis under given data, and inverse Bayesian inference by replacing the conditional probability of data under a hypothesis with the probability of data [16,17]. Such a mixture of the probability and the conditional probability can entail dynamic negotiation of microscopic and macroscopic views. Indeed, we apply an idea of a pair of Bayesian and inverse Bayesian inference to the agent based model for a swarm [18].

In [14,15], such implementation can be expressed as Orthomodular lattice which is a lattice expression of quantum logic. While Orthomodular lattice does not need Hilbert space, it does not imply inconsistency between bio-inspired computation and quantum logic, but imply much more stronger conjecture that bio-inspired computation featuring dynamic interface between microscopic and macroscopic computation can involve quantum mechanics and/or quantum logic as a part of it.

Since Gao et al. extend various physarum motivated computing [19,20] and consider the limit of physarum inspired computing, they can reach hybrid optimization coupled with ant colony algorithm [21]. Although it is still unclear to see the dynamic interface between microscopic and macroscopic mechanisms which can be transformed to quantum logic or quantum theory. We think that quantum theory can be a part of bio-inspired computing theory, which would be called macroscopic quantum theory which is not related to quantum mechanism as physical base but related to it as informational base. That is a hopeful candidate to construct theory of consciousness. In this sense physarum inspired computing can provide a new idea on proto-cognition [22].

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