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Physics of Life Reviews 29 (2019) 48–50

PHYSICS of LIFE reviews

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Comment

Can bio-inspired optimization algorithms be used to further improve the collective computing performance? Comment on review article "Does being multi-headed make you better at solving problems? A survey of Physarum-based models and computations" by Chao Gao et al.

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Received 25 December 2018; accepted 15 January 2019
Available online 18 January 2019
Communicated by J. Fontanari

Keywords: Bio-inspired optimization algorithms; Physarum-based models; Computational applications

Inspired by the evolution of biological systems and collective behaviors of social insects, many researchers began to borrow the ideas and methods from these fields to devise the novel algorithms to carry out the iterative computation and optimization analysis, and even resolve some classical NP-hard problems, or greatly enhance the efficiency and stability of computing and controlling approaches for those kinds of problems, to name but a few, genetic algorithms (GA) [1,2], ant colony optimization (ACO) algorithms [3,4] and so on. In this comprehensive review [5], Gao et al. survey the recent progresses in the field of evolutionary computing, especially for *Physarum*-based modeling and computing techniques, and aim to provide some help for readers to deeply understand the profound mechanisms behind the population intelligence and/or even propose some brand-new algorithms to resolve the complex computational problems.

As the rapid development of intelligent computing techniques, the extensive works are devoting to the *Physarum*-based modeling and applications, where *Physarum* can often be considered as a simple organism exhibiting a complex and intelligent behavior without any central control, to some extent, during the process of its extension and forging, and can also adaptively accommodate the dynamical evolution of systems. To perform a quantitative and accurate analysis or comparison for the existing works, the authors firstly select the *Physarum*-related references since 2000 from the Web of Science with the keywords "*Physarum* model" and its equivalent terms "amoeba model", and then

DOI of original article: https://doi.org/10.1016/j.plrev.2018.05.002.
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https://doi.org/10.1016/j.plrev.2019.01.003

utilize the network science [6–8] methods to build a citation network on top of the most cited 100 papers and their citing references. Finally, they again make use of the community detection algorithm in complex networks to classify the whole network into several clusters, in which each cluster denotes a main research domain or an independent section reviewed here. To the best of our knowledge, it may be the first review on a specific topic in our journal starting from a citation relationship based on the network science.

After a brief overview of *Physarum*-related literatures, according to the results of community division, this review particularly focuses on the analyses and potential applications of *Physarum*-based models, which can be summarized as the following three main aspects:

- Morphology-based models and their computational applications. The morphology of *Physarum polycephalum* denotes the adaptability to changes in the environment and is often modeled with the cellular automata (two important works are termed as CELL model and VP-S model in [5]), and this type of models are often used to design more effective and/or efficient man-made transportation networks in an approximate, yet computationally economic manner.
- Taxis-based models and their computational applications. The taxis represents the *Physarum*'s ability to regulate its movement to trends in the composition of surrounding environments. This type of models are primarily divided into two classes: top-down and bottom-up models, which are presented to understand the underlying reasons for taxis of protoplasmic extension from the perspective of global (macro-level) and local (micro-level) interactions, respectively. The taxis-based models can be applied into various domains of the optimization-design problems, which cover the network planning, maze conquering and optimal route selection, and graph mining etc.
- Dynamics-based models and their computational applications. Considering the feedback relationship between the information flux inside the *Physarum*'s tubes and their thickness, many works resolved the optimization problems by exploiting this kind of positive feedback dynamics [9–11], and built the corresponding mathematical formalism as illustrated in equations and network representations in [5] (p. 4). As these models can help to find the shortest paths without any central control and adaptively regulate the network design, they are integrated into various optimization problems which include the network and route planning, linear transportation planning and efficient network configuration finding, 0/1 knapsack and traveling salesman problem's resolution, and even devising the hybrid optimization algorithms and so on. In addition, as mentioned above, this review makes use of the community detection, which is a long-standing problem in the structural analysis of complex networks [12–14], to conduct the literature classification comparison, and the authors has also explored the potential role of *Physarum*-based algorithms in the community division aiming to improve the performance of community detection with the help of dynamics-based models.

Taking together, this review provides an extensive and comprehensive description about the *Physarum*-inspired algorithms so that the readers can make an exhaustive and quick view of *Physarum*-based modeling and optimization techniques. However, we have still several potential questions to be negotiated here as follows:

- *Physarum*-based models greatly enhance their adaptability facing the dynamical changing environments, but the authors do not perform the time and/or space complexity analysis regarding some specific algorithms when compared to the traditional intelligent algorithms. Thus, what are the main factors impacting the running performance of related models and algorithms? Additionally, as the size to be resolved problems increases, can *Physarum*-inspired algorithms further enhance the computing efficiency? Is it necessary to search for another organism to build the bio-inspired algorithms?
- Real-world systems are often highly networked, and various subsystems are interrelated and/or interdependent, while the current *Physarum*-based models generally do not consider the role of complex topology in modeling the evolution of dynamics on top of multiplex or multi-layer networks [15,16]. As an example, during the evolutionary game decision [17,18] when there exists the conflict between an individual and collective interest, how can the *Physarum*-based models be combined with the game dynamics on complex networks to explore the collective self-organization and emergent behavior within the insect population? Can *Physarum*-based models help us to resolve the social dilemmas or find a better solution to illustrate the evolution of cooperation?
- New generation information and communication technology (ICT) increasingly influences and even gradually changes the way that human beings work, learn and even lives. Can *Physarum*-based models further be introduced

into ICT systems to accelerate the information acquisition, storage, transmission and even processing? In addition, with the development of the machine learning or neural network algorithms, can we combine these techniques to further enhance the quality of intelligent optimization systems under the data-driven environments, in particular for the systems with the small data or samples?

We expect the responses from the authors of Ref. [5] regarding the above-mentioned problems, which will help the readers to deeply understand various ways of *Physarum*-modeling techniques and their corresponding applications.

To sum up, the current review offers some valuable clues for scientists to extend the existing optimization approaches into more applications and even devise some novel algorithms with the help of *Physarum*-based models. Meanwhile, the deep understanding of the intrinsic mechanisms on the *Physarum* evolutionary behavior is beneficial for us to further characterize the collective behavior on the level of population, whether for the insect or the human society. Finally, we strongly agree with Gao et al. that *Physarum polycephalum* thus seems to solve a range of different optimization problems, and its behavior is also well-studied, which will continue to be studied and inspire scientists in the future.

Acknowledgements

This project is financially supported by the National Natural Science Foundation of China (NSFC) (Grant nos 61773286 and 71401122), and CY Xia also acknowledges the support of China Scholarship Council (under Grant no. 201808120001).

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