Adaptive dynamics for shape optimization inspired by the use-and-growth rule in a simple organism of slime mold

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ABSTRACT

A kind of huge amoeboid organism named *Physarum* plasmodium constructs a intricate network of veins for circulating nutrients and signals over the entire body. The network shape (topology of connectivity and sequence of branching in vein network, for instance) is drastically re-organized within an hour in response to external conditions. The past studies showed that the network shape was optimized to maximize possibility of survival, in some sense. So we may extract an algorithm for optimal design of functional network from the primitive organism. The key thing to design is adaptive dynamics of current-reinforcement rule: each vein of network becomes thicker when current is large enough through the vein itself, while it becomes thinner and dies out otherwise. Based on this simple rule, functions and formation of transport network in *Physarum* is analyzed. We will show that the rule is applicable to the other bio-systems: (1) social dynamics of public transportation, (2) formation of network structure in porous tissues bone (bone remodeling in other words), (3) fibrous tissue of plants and fungi. A tractable perspective to think similarly of a variety of bio-network is given from the viewpoint of current-reinforcement rule.

Categories and Subject Descriptors

C.2.2 [**Network Architecture and Design**]: Distributed networks; G.1.5 [**Optimization**]: Nonlinear programing; H.1 [**Models and principles**]: Miscellaneous

Keywords

transport network, *Physarum*, cell mechanics, pattern formation, ethology, intelligent system, autonomous decentralized system, mathematical modeling

1. TRANSPORT NETWORK IN LIVING SYSTEMS

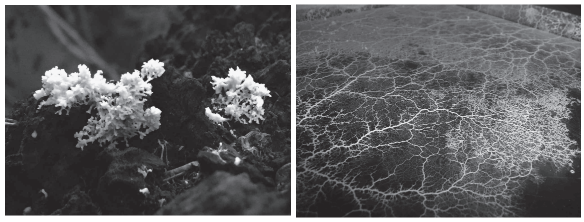

Figure 1: Pictures of *Physarum* plasmodium in the wild (left) and in the laboratory (right).

Network of transport is found in a wide range of living system. The typical examples, on the three main multicellular branches of phylogenetic tree, are vascular network in vertebrates and tracheal network in vascular plants, and hyphal network in fungi. These organisms consist of a large number of cell (approximately 60,000,000,000,000 cells of a human body and 100,000,000,000,000 cells of bacterium in the gastrointestinal lumen of human, as one of estimated numbers) and it is necessary to maintain exchange of materials and signals enough to be a unified system over a whole range of body. One may expect that the network enables it.

Such a network structure is found in self-organized colony of unicellular bacteria: a biofilm that is a sheet-like aggregate of many bacteria and sticky polysaccharides secreted from the bacteria. This network is not as well-organized as the multicellular organisms ’ones but some of physiological function is expected as discussed in the literature. Comparative study of various kinds of bio-network of transport along phylogenetic tree is probably interesting since an insight into evolutionarily sophisticated designing of adaptive network is obtained in a wider perspective.

2. TRANSPORT NETWORK IN PHYSARUM PLASMODIUM

At the interface between unicellular and multicellular branches, which is around the root of eukaryotic branch, there is an unique organism with highly flexible body shape with network structure, true slime mold Myxomycete (or Mycetozoa). *Physarum polycephalum* Schw, the most used species of true slime mold in cell biology and biophysics last seventy years although several hundreds of species are known so far, have shown a hint at a proper way to comparative study of

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bio-network for the last one or two decade(s). That 's because *Physarum* plasmodium (' plasmodium 'is a vegetative stage of life cycle in diploid phase) is a very helpful model organism to work with: (1) not only drastic but also fast (in hours) changes in network topology in response to external conditions, (2) rich knowledge of cell movement and tactic behavior, (3) macroscopic homogeneity of body that looks like an aggregate of cytosol (or autonomous decentralized organization of cytosol in other words) in case of applying physical equations of motion into plasmodial network, (4) high visibility of network morphology, (5) economical cost for feeding and culture, (6) results from genome project, etc.

3. NETWORK TOPOLOGY AND TRANSPORT CAPACITY IN PHYSARUM NETWORK

Concerning *Physarum* network, our interests have focused on (1) function and capacity of transport, (2) macroscopic and microscopic mechanics for morphogenesis and formation of network architecture (topology, thickness, length, branching, coverage, etc), (3) comparison with the other transport networks of living and nonliving system, (4) application of insight to the other domains of science and technology, (5) review of history of bio-network in general, (6) sharing the obtained findings and insights with a wide range of people and feed back from them, by means of arts, Manga, mass-media, community-based activities, outreach to school, popular science book and so on.

Here in this presentation, we will show our current topics on *Physarum* network: (1) hydrodynamic evaluation of transport capacity, (2) comparative study with adaptive formation of network structure in bone remodeling.

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