

Analysis on the exploratory behavior of the *Physarum* plasmodium in an open space

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ABSTRACT

True slime mold *Physarum polycephalum* is a unicellular and multinuclear giant organism. Recent years, it has been demonstrated that the organism has computational abilities. For example, the previous studies demonstrated that plasmodium can solve a maze and optimize a network between multiple food sources. These are the examples of spatial optimization by the plasmodium in a closed space. On the contrary, there are not many studies on the behavior of the plasmodium in an open space and on how the organism adapts itself to the open environment. In this study, we thus developed an experimental system with a large and highly uniform substrate and realized the analysis on the exploratory behavior in a very wide, a substantially open space. In the exploratory pattern of the plasmodium in this setup, we found a new power-law distribution. This work was presented at PhysNet 2015.

Categories and Subject Descriptors

J.3 [Computer Applications]: Life and Medical Sciences – biology and genetics

Keywords

Physarum plasmodium, exploratory behavior, power-law, cell motility

1. INTRODUCTION

The plasmodium of *Physarum polycephalum* is a unicellular and multinuclear giant amoeba, which is formed by the fusion of myriad of uninucleate cells. In an appropriate condition, the plasmodium grows to the visible scale (Figure 1). Though the plasmodium has a simple and homogeneous structure, in the previous studies, it is demonstrated that the plasmodium has computational abilities. For example, the plasmodium can solve a maze [1]. If the plasmodium is supplied with two nutrient sources after the organism has fully searched the maze-space, the plasmodium finds the shortest path between the nutrients. The plasmodium is also able to optimize a network between multiple food sources [2]. If multiple food sources are supplied to the plasmodium fully searched a closed space, the plasmodium forms an efficient network in terms of total length and fault tolerance. As exemplified above, the plasmodium has abilities of spatial optimization and geometrical computation, however, almost all of the previous studies investigate the behaviors of the plasmodium in a closed space, and there is not many studies on the behaviors of the organism in an open space.

In this study, we thus developed a new experimental system with large and highly homogeneous substrate to study the long term exploratory behavior of the plasmodium in a substantially open space and how the organism adapts itself to the open and unknown environment.

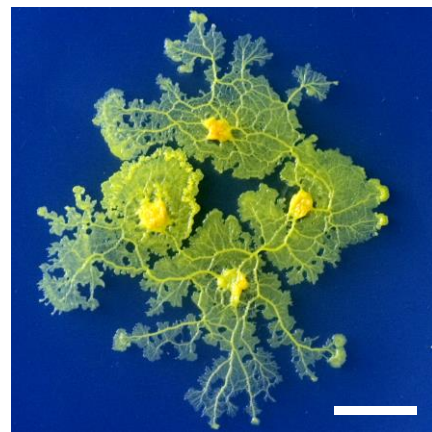


Figure 1. The *Physarum* plasmodium crawling on a 1.5 % non-nutrient agar plate. (Bar: 1 cm).

2. MATERIALS AND METHODS

To prepare a large experimental field to observe the long term exploratory behavior of the plasmodium, we used a 106 cm × 106 cm × 4.5 cm plastic box and a 1 m × 1 m × 3 cm melamine sponge placed in the box. The sponge was soaked with sufficient amount of water, and the water was kept being supplied throughout the experiment. The excessive water was drained. The melamine sponge was covered by a black cloth to provide a black background for the photographing, and further, the cloth was covered by a cellophane sheet to provide a substrate for the plasmodium (Figure 2).

The whole experimental setup was illuminated by using 600 nm yellow light emission diode that does not induce negative phototaxis of the plasmodium. In the experiments, 10 mg, 30 mg, 100 mg and 300 mg of the plasmodia were used and in each experiment they were inoculated at the center of the substrate. The motility of the plasmodium was recorded by a digital camera (EOS 5D Mark II, Canon, Japan) at 2 minute-intervals from directly above. From the images, the center of mass of the plasmodium at each time was calculated by using an image processing software ImageJ [3], and the speed and the direction of motility was analyzed based on the center of mass (Figure 3).

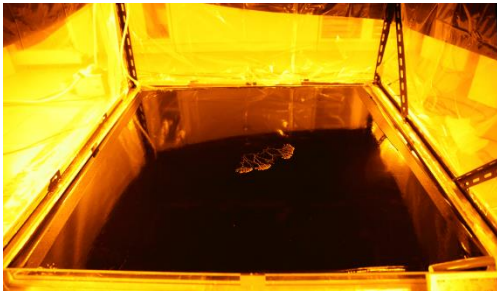


Figure 2. The experimental setup. The size of the substrate is 1 m × 1 m, and the setup is enclosed by a plastic sheet to keep the moisture inside.

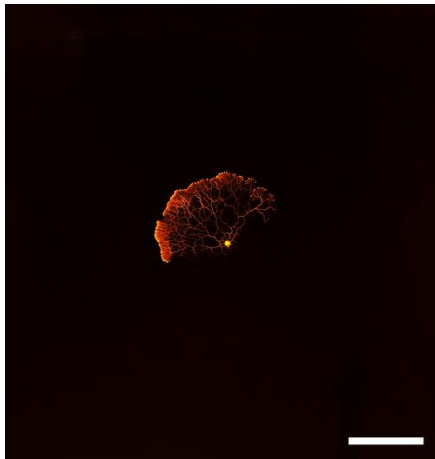


Figure 3. The image of the plasmodium obtained by using the setup shown in Figure 2. (Bar: 10 cm)

3. RESULTS AND DISCUSSION

In this section, we describe the results from the experiments using 30 mg plasmodium. The speed of the plasmodium was 2.07 cm/h in average, and ranged from 0 – 14.0 cm/h. The frequency distribution of the speed is illustrated in Figure 4, and the double logarithmic plot of Figure 4 is shown in Figure 5. In Figure 5, the plots were fitted with double power-law distribution by using maximum likelihood estimation and Kolmogorov-Smirnov test, and the values of the exponents are 2.35 in the right half and 0.76 in the left half.

The pattern of the distribution in Figure 5 is similar to that of Lévy flight. Lévy flight is a kind of random walk and its frequency distribution of locomotive distance d in one step is defined by $f(d) = k \cdot d^{-\lambda}$ ($1 < \lambda < 3$). This exploratory pattern is thought to be effective in exploring rare targets in a large space [4], and found in the exploratory patterns in animals and birds. It is surprising that such a pattern is also found in the unicellular organism, and this pattern may contribute to the exploratory efficiency of the plasmodium.

In conclusion, we succeeded to establish an experimental setup with large and highly homogeneous substrate to observe the long term exploratory behavior of the plasmodium, and as a result, we found a new exploratory pattern with power-law distribution that is similar to Lévy flight.

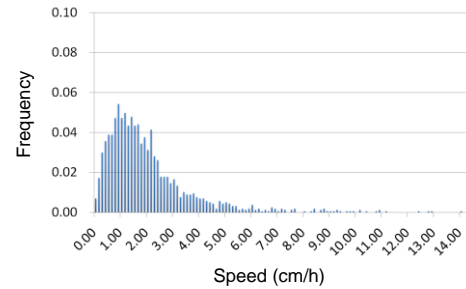


Figure 4. Frequency distribution of the speed of the plasmodial motility.

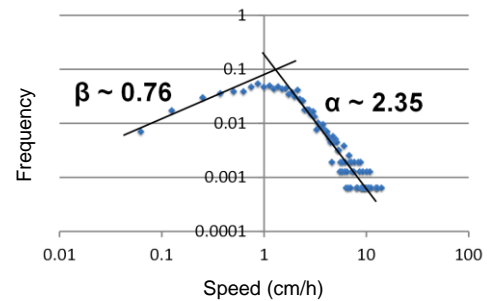


Figure 5. Double logarithmic plot of the frequency distribution illustrated in Figure 4.

4. REFERENCES

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