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On Building Practical Biocomputers for Real-world Applications: Receptacles for Culturing Slime Mould Memristors and Component Standardisation

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Abstract

Our application of bionic engineering is novel: we are interested in developing hybrid hardware-wetware systems for music. This paper introduces receptacles for culturing *Physarum polycephalum*-based memristors that are highly accessible to the creative practitioner. The myxomycete *Physarum polycephalum* is an amorphous unicellular organism that has been found to exhibit memristive properties. Such a discovery has potential to allow us to move towards engineering electrical systems that encompass *Physarum polycephalum* components. To realise this potential, it is necessary to address some of the constraints associated with harnessing living biological entities in systems for real-time application. Within the paper, we present 3D printed receptacles designed to standardise both the production of components and memristive observations. Subsequent testing showed a significant decrease in growth time, increased lifespan, and superior similarity in component-to-component responses. The results indicate that our receptacle design may provide means of implementing hybrid electrical systems for music technology.

Keywords: unconventional computing, *Physarum polycephalum*, computer music, biological computing, memristor

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1 Introduction

Our research is concerned with engineering unconventional and novel hybrid hardware-wetware computing systems for music and sound. In computer music, there is a tradition of experimenting with emerging technologies. Until recent years, developments put forward by the field of unconventional computation have been left unexploited, which is likely due to the field's heavy theoretical nature, complexity, and the lack of accessible prototypes. In our research, we have been experimenting with the biological computing substrate *Physarum polycephalum*, referred to in this paper as *P. polycephalum*, for computer music. *P. polycephalum* is an ideal candidate for research into biological computing for music due to its accessibility: unlike many other biological computing substrates, *P. polycephalum* is safe to use, cheap, requires few resources to develop prototypes, and is fairly robust. Thus, by developing systems with *P. polycephalum*, we can widen the application of unconventional computing schemes in computer music by enticing and inviting other practitioners to experiment and create artefacts with the systems we develop. It is hoped that other communities interested in unconventional computing would also benefit from our research.

P. polycephalum is a myxomycete that, in its vegetative plasmodium form, exists as an amorphous unicellular organism, which propagates on gradients of stimuli while laying down an efficient transport network of protoplasmic tubes (Fig. 1). The plasmodium, although without a brain or any serving centre of control, can respond with natural parallelism to the environmental conditions that surround it. Researchers have harnessed such abilities to develop a wide range of computing and sensing schemes. Some examples include logic gate systems[1], robot control[2], and path finding[3]. See Ref. [4] for a collection and excellent guide on computing with *P. polycephalum*.

In 2011 Miranda *et al*. reported on preliminary work with *P. polycephalum* for computer music[5]. In this study, the team developed a sound synthesis framework to create a bionic instrument using recordings of *P. polycephalum*'s extracellular membrane

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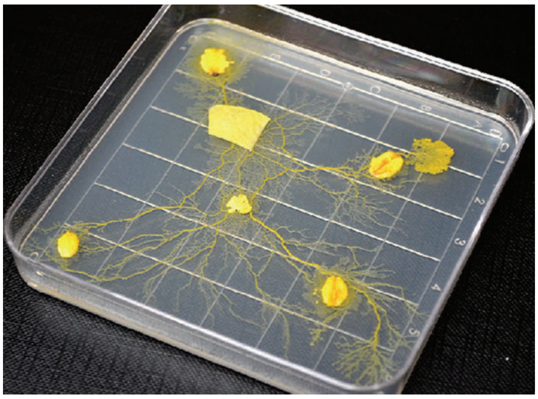

Fig. 1 A culture of the plasmodium of *P. polycephalum* within a square Petri dish. The figure depicts a network of protoplasmic veins laid down by a propagating fanlike structure of pseudopods.

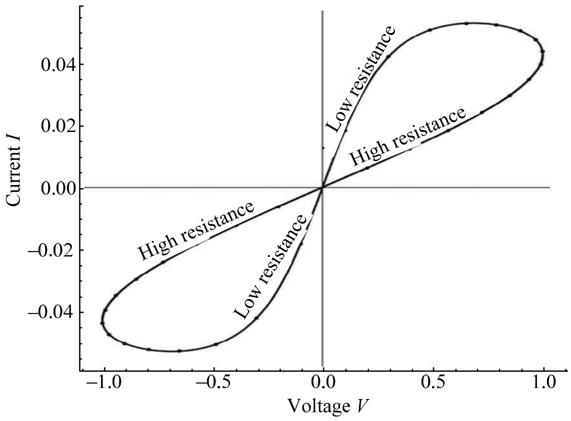

Fig. 2 Example of hysteresis in an ideal memristor (arbitrary values used).

potential. We further developed this offline approach to harnessing the organism in several different musical applications: step sequencers[6], granular synthesis[7], and contemporary composition[8], to cite but three. From these research progresses, we were able to confirm that *P. polycephalum* exhibits properties that can be harnessed to implement systems for generative audio and music. However, we were conscious that we needed to move on to develop and study systems beyond offline sonification in order to progress with our research.

In 2003 Gale *et al.*[9] demonstrated in laboratory experiments that the protoplasmic tube of *P. polycephalum* can act as an organic memristor. Memristors[10] are the recently discovered[11] fourth fundamental passive circuit component that relates magnetic flux linkage and charge. Unlike the other passive elements, namely the capacitor, inductor, and resistor, the memristor is non-linear and possesses a memory. The I-V footprint of this component, when applied with an AC voltage, is a pinched hysteresis loop-a Lissajous figure formed by two perpendicular oscillations creating a high and low resistant state. In an ideal memristor, hysteresis is observed as a figure of 8 where the centre intersection is at both zero voltage and current (Fig. 2). We can describe memristance using a state-dependant Ohms law, which is mathematically denoted below:

$$M = R(q) = \frac{\mathrm{d}\varphi(q)}{\mathrm{d}q},$$

where q is charge and φ is flux[10].

Computer scientists have a keen interest in experimenting with the memristor, which is due, in major part, to properties that have promise to revolutionise the way our computers work. Investigators have credited memristors as being the first to combine processing and memory abilities in a single component[12]. The discovery that *P. polycephalum* can act as a memristor is providing researchers with an unprecedented opportunity to begin developing everyday information processing systems using biological components. In regards to our research, the discovery has offered us a pathway to designing hardware-wetware systems for real-time musical application: a large step forward from the preliminary work article we published in 2011[5].

We have developed novel ways of generating musical responses by harnessing the memristor's non-linear ability to alter its resistance as a function of both its current input and history of previous inputs: an ability that is musically relatable. For a summary of our creative work with memristors see Ref. [13]. Using our research progresses, in Ref. [14] we developed a hardware-wetware system to take outside of the laboratory and immerse into real-time live performance. Our system consisted of *P. polycephalum* components that we grew in individual Petri dishes furnished with electrodes. As an overview, the system functions by a computer program transcribing a live pianist's performance into voltages that together form a complex AC waveform. This waveform passes through the *P. polycephalum*-based memristors whose subsequent current readings are measured and translated into a musical response that our system plays on the same piano via electromagnets positioned above the strings[15]. A recording of a performance using our system can be found at Ref. [16].