Int. Journ. of Unconventional Computing, Vol. 8, pp. 319–323
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Physarum Chip Project: Growing Computers From Slime Mould

ANDREW ADAMATZKY[1,*], VICTOR EROKHIN[2], MARTIN GRUBE[3], THERESA SCHUBERT[4] AND ANDREW SCHUMANN[5]

[1]*Unconventional Computing Centre, University of the West of England, Bristol, United Kingdom*
[2]*CNR-IMEM and Department of Physics, University of Parma, Italy*
[3]*Institute of Plant Science, University of Graz, Austria*
[4]*Faculty of Media, University of Weimar, Germany*
[5]*University of Information Technology and Management, Rzeszow, Poland*

Received: July 16, 2012. Accepted: July 16, 2012.

Keywords: Unconventional computing, slime mould, nature-inspired computing, Physarum polycephalum

1. INTRODUCTION

Research in unconventional, or nature-inspired, computing aims to uncover novel principles of efficient information processing and computation in physical, chemical and biological systems, to develop novel non-standard algorithms and computing architectures, and also to implement conventional algorithms in non-silicon, or wet, substrates. This emerging field of science and engineering is predominantly occupied by theoretical research, e.g. quantum computation, membrane computing and dynamical systems computing.

Despite the profound potential offered by unconventional computing, only a handful of experimental prototypes are reported so far, for example gas-discharge analog path finders; maze-solving micro-fluidic circuits; geometrically constrained universal chemical computers; specialized and universal chemical reaction--diffusion processors; universal extended analog computers; maze-solving chemo-tactic droplets; enzyme-based logical circuits; spatially extended crystallization computers for optimization and computational geometry; molecular logical gates and circuits.

*Corresponding author: andrew.adamatzky@uwe.ac.uk

A weak representation of laboratory experiments in the field of unconventional computers could be explained by technical difficulties, costs of prototyping of novel computing substrates, and also psychological barriers. Chemists and biologists do not usually aspire to experiment with unconventional computers with unconventional computers because such activity diverts them from mainstream research in their fields. Computer scientists and mathematicians would like to experiment but are scared of laboratory equipment. If there was a simple to maintain substrate, which requires minimal equipment to experiment with and whose behaviour is understandable by and appealing to researchers from all fields of science, then progress in designing novel computing devices would be much more visible. We offer slime mould Physarum polycephalum for a role of such a 'universal' computing substrate.

2. CONCEPTS AND OBJECTIVES

Physarum polycephalum belongs to the species of order *Physarales*, subclass *Myxogastromycetidae*, class *Myxomycetes*, division *Myxostelida*. It is commonly known as a true, acellular or multi-headed slime mould. Plasmodium is a 'vegetative' phase, a single cell with a myriad of diploid nuclei. The plasmodium is visible to the naked eye. The plasmodium looks like an amorphous yellowish mass with networks of protoplasmic tubes. The plasmodium behaves and moves as a giant amoeba. It feeds on bacteria, spores and other microbial creatures and micro-particles [1].

The unique features of P. polycephalum are following [2]:

- Physarum is a living, dynamical reaction-diffusion pattern formation mechanism.
- Physarum may be considered as equivalent to a membrane bound sub excitable system (excitation stimuli provided by chemo-attractants and chemo-repellents).
- The complex patterning (reticulate networks, dendritic patterns) is equivalent to parts of the continuum of Turing structure patterns.
- Physarum efficiently exploits — or *outsources* — external computation by the environment via the sensing and suppression of nutrient gradients
- Physarum may be regarded as a highly efficient and living micromanipulation and micro-fluidic transport device
- The induction of pattern type is determined partly by the environment, specifically nutrient quality and substrate hardness, dryness etc.
- Physarum is thus a computational material based on modification of protoplasm transport by presence of external stimuli.

FIGURE 1
Slime mould *P. polycephalum*.

- Physarum is sensitive to illumination and AC electric fields and therefore allows for parallel and non-destructive input of information
- Physarum represents results of computation by configuration of its body.

We will design and fabricate a distributed biomorphic computing device built and operated by slime mould P. polycephalum. A Physarum chip is a network of processing elements made of the slime mould's protoplasmic tubes coated with conductive substances; the network is populated by living slime mould. A living network of protoplasmic tubes acts as an active non-linear transducer of information, while templates of tubes coated with conductor act as fast information channels.

The Physarum chip will have parallel inputs (optical, chemo- and electro-based) and outputs (electrical and optical). The Physarum chip will solve a wide range of computation tasks, including optimisation on graphs, computational geometry, robot control, logic and arithmetical computing. The slime mould-based implementation is a bio-physical model of future nano-chips based on biomorphic mineralisation.

We envisage that research and development centred on novel computing substrates, as self-assembled and fault-tolerant fungal networks will lead to a revolution in the bio-electronics and computer industry. Combined with conventional electronic components in a hybrid chip, Physarum networks will radically improve the performance of digital and analog circuits.

3. OUTCOMES

The project will deliver proof-of-concept for highly innovative biomorphic information technology based on hybrid live and conductor-coated slime mould devices that are:

- analogous to reaction-diffusion chemical systems encapsulated in a growing elastic membrane
- combining dead (but coated with conductors) and living parts of slime mould in communication channels
- powered directly and efficiently by bio-chemical power
- fabricated using self-growth and self-organisation
- controllably shaped into two- and three-dimensional structures
- interfaced with conventional technology (optically or electronically) as well as via chemical means
- responding to distinct activating and inhibiting stimuli
- flexible with regards to the computing paradigm they implement; possessing a broad menu of options to side-step unforeseen difficulties or specialise for certain application domains
- robust to physical damage and exhibit a degree of self-repair.
- The fabricated Physarum chip will perform computation by classical means of electrical charge propagation, by travelling waves of contraction, and by physical propagation of structures.

In terms of classical computing architectures, the following characteristics can be attributed to Physarum chips:

- Massive parallelism: there are thousands of elementary processing units, oscillatory bodies, in a slime mould colonised in a Petri dish;
- Massive signal Integration: Membrane of plasmodium is able to integrate massive amounts of complex spatial and time-varying stimuli to effect local changes in contraction rhythm and, ultimately, global behaviour of the plasmodium;
- Local connections: micro-volumes and oscillatory bodies of cytoplasm change their states, due to diffusion and reaction, depending on states of, or concentrations of, reactants, shape and electrical charges in their closest neighbours;
- Parallel input and output: Physarum computers by changing its shape, can record computation optically; Physarum is light sensitive, data can be inputted by localized illumination;
- Fault tolerance: being constantly in a shape changing state, Physarum chip restores its architecture even after a substantial part of its protoplasmic network is removed.

Taking into account the enormous and growing interest of research centres and commercial laboratories in the recent experimental implementations of chemical, molecular and biological computers, we can predict that in the next 20-30 years, networks of slime mould mineralised and/or coated with compound substances will become a widespread commodity and a very promising component of novel information processing circuits.

REFERENCES

[1] Stephenson S. L. and Stempen H. Myxomycetes: A Handbook of Slime Molds. (Timber Press, 2000).
[2] Adamatzky A. Physarum Machines (World Scientific, 2010).