Chapter 17

Trans-Canada Slimeways: Slime Mould Imitates the Canadian Transport Network

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ABSTRACT

Slime mould Physarum polycephalum builds up sophisticated networks to transport nutrients between distant parts of its extended body. The slime mould’s protoplasmic network is optimised for maximum coverage of nutrients yet minimum energy spent on transportation of the intra-cellular material. In laboratory experiments with P. polycephalum we represent Canadian major urban areas with rolled oats and inoculated slime mould in the Toronto area. The plasmodium spans the urban areas with its network of protoplasmic tubes. The authors uncover similarities and differences between the protoplasmic network and the Canadian national highway network, analyse the networks in terms of proximity graphs and evaluate slime mould’s network response to contamination.

1. INTRODUCTION

The increase of long-distance travel and subsequent reconfiguration of vehicular and social networks (Larsen, Urry, & Axhausen, 2006) requires novel and unconventional approaches towards analysis of dynamical processes in complex transport networks (Barrat, Barthelemy, & Vespignani, 2008) routing and localisation of vehicular networks (Olariu & Weigle, 2009) optimisation of interactions between different parts of a transport network during scheduling road expansion and maintenance (Taplin, Qiu, & Han, 2005) and shaping of transport network structure (Beuthe, Himanen, Reggiani, & Zamparini, 2004). The main goals of the paper are to uncover viable analogies between biological and human-made transport networks and to project behavioural traits of biological networks onto existing vehicular transport networks.

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While choosing a biological object we want it to be experimental laboratory friendly, easy to cultivate and handle, and convenient to analyse its behaviour. Ants would indeed be the first candidate, and a great deal of impressive results has been published on ant-colony inspired computing (Dorigo & Stutzle, 2004; Solnon, 2010), however ant colonies require substantial laboratory resources, experience and time in handling them. Actually very few, if any, papers were published on experimental laboratory implementation of ant-based optimisation, the prevalent majority of publications being theoretical. There is however an object which is extremely easy to cultivate and handle, and which exhibits remarkably good foraging behaviour and development of transport networks. This is the plasmodium of *Physarum polycephalum*.

Plasmodium is a vegetative stage of acellular slime mould *P. polycephalum*, a syncytium, that is, a single cell with many nuclei, which feeds on microscopic particles (Stephenson & Stempen, 2000). When foraging for its food the plasmodium propagates towards sources of food particles, surrounds them, secretes enzymes and digests the food. Typically, the plasmodium forms a congregation of protoplasm covering the food source. When several sources of nutrients are scattered in the plasmodium’s range, the plasmodium forms a network of protoplasmic tubes connecting the masses of protoplasm at the food sources.

A life cycle of *P. polycephalum* is as following. When plasmodium is deprived of water or nutrients it switches to ‘hibernation’ mode and forms a hardened mass called sclerotium. Sclerotium can survive without food or water for years. When moistened, the sclerotium returns to the state of plasmodium. When exposed to bright light and starved, the plasmodium switches to fructification phase. It grows sporangia. When a spore gets into a favourable environment, it releases a single-cell myxamoeba. Myxamoebas can live as they are for a long time. In the presence of water a myxamoeba is transformed into a swarm cell with two flagellas. Swarm cells can swim. Myxamoebas and swarm cells can reproduce asexually, by simple division. During changes of environment from good to bad, myxamoebas and swarm cells can form spheroidal micro-cysts with cellulose walls. When enough myxamoebas or swarm cells are present in the volume, they begin sexual reproduction and form a zygote. The zygote divides mitotically and forms a multi-nuclear single cell — the plasmodium.

The plasmodium is a unique user-friendly biological substrate from which experimental prototypes of massive-parallel amorphous biological computers are designed (Adamatzky, 2010). During its foraging behaviour the plasmodium spans scattered sources of nutrients with a network of protoplasmic tubes. The protoplasmic network is optimised to cover all sources of food and to provide a robust and speedy transportation of nutrients and metabolites in the plasmodium body. The plasmodium’s foraging behaviour can be interpreted as computation. Data are represented by spatial configurations of attractants and repellents, and results of computation by structures of a protoplasmic network formed by the plasmodium on the data sets (Nakagaki, Yamada, & Ueda, 2000). (Nakagaki, Yamada, & Toth, 2001; Adamatzky, 2010). The problems solved by plasmodium of *P. polycephalum* include shortest path (Nakagaki, Yamada, & Ueda, 2000; Nakagaki, Yamada, & Toth, 2001) implementation of storage modification machines (Adamatzky, 2007b). Voronoi diagram (Shirakawa, Adamatzky, Gunji, & Miyake, 2009), Delaunay triangulation (Adamatzky, 2010), logical computing (Tsuda, Aono, & Gunji, 2004), and process algebra (Schumann & Adamatzky, 2009); see overview in Adamatzky (2010).

Previously (Adamatzky, 2007a) we have evaluated a road-modeling potential of *P. polycephalum*, however no conclusive results were presented back in 2007. A step forward, namely, biological-approximation, or evaluation, of human-made road networks was done in our previous papers on approximation of motorways/highways in the United Kingdom (Adamatzky & Jones, 2010),

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