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ABSTRACT: Networks created by the slime mould *Physarum polycephalum* have been the object of interdisciplinary studies and artistic interventions for more than two decades. This paper examines different practices of abstracting humans' and slime mould's lines of movement into networks and investigates how *Physarum* networks are used to explore human patterns of movement and vice versa. It argues that, far from anthropomorphizing the slime mould, the effect of these experiments is instead a slimy rendering of the human.

KEYWORDS: *Physarum polycephalum*; network; lines; slime mould; transportation systems; models

The Slime Mould's Many Bodies, or Modelling Networks with *Physarum polycephalum*

MARIA DĘBIŃSKA

The shining path of humanity is only ever the
verminous-like trail of our own oozing across
time and space — the trace and proof of our
complete sliminess through and through.

Ben Woodard, *Slime Dynamics*¹

Physarum polycephalum is a chimeric creature combining characteristics of fungi and animals, which at a certain stage of its life cycle forms a yellow blob that crawls around forming complex networks, captivating scientists and lay people alike. The simplicity of its structure and simultaneous complexity of its behaviour invite experimentation and have inspired investigations into the nature and origins of intelligence, memory, learning, and sociality. The peculiarity of this organism, a

* This paper is based on research funded by the National Science Centre (Poland), grant no. 2019/33/B/HS3/02332.

1 Ben Woodard, *Slime Dynamics: Generation, Mutation, and the Creep of Life* (Winchester: Zero Books, 2012), p. 67.

pulsating bag of slime that can perform complicated tasks, turns it into a productive ‘epistemic thing’, an instrument to think with.²

In the laboratory context *Physarum* is most commonly used as a model organism by biologists and biophysicists in numerous areas of research, such as basal cognition,³ cell ageing,⁴ cell aggregation, and the emergence of collective behaviours,⁵ to name just a few. However, due to the fact that it is relatively easy and safe to cultivate (it does not demand sterile conditions and its favourite food is common oats), *Physarum* also lends itself as a model for sociocultural phenomena, especially human-made networks and emergent social processes. In the projects discussed in this chapter, *Physarum*’s function as a model expands to new territories of art, mathematics, and computer science; the slime mould retains some of the characteristics of a model organism,⁶ but also acquires new ones, which turn it into a speculative device, a catalyst for new narratives and imaginaries of the social.

The focus of this paper is experiments mapping human-made networks of movement and transportation, since this is the area in which comparisons between the slime mould and humans impose themselves most forcefully and in which the analogies are most pronounced. In the preface to a collected volume devoted exclusively to recreating human transportation systems with *Physarum*, Andrew Adamatzky recalls his first encounter with the slime mould:

2 Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, CA: Stanford University Press, 1997).

3 Pamela Lyon and others, ‘Reframing Cognition: Getting Down to Biological Basics’, *Philosophical Transactions of the Royal Society B*, 376 (2021) <<https://doi.org/10.1098/rstb.2019.0750>>.

4 Angèle Rolland and others, ‘Behavioural Changes in Slime Moulds over Time’, *Philosophical Transactions of the Royal Society B*, 378 (2023) <<https://doi.org/10.1098/rstb.2022.0063>>.

5 Sheryl Hsu and Laura Schaposnik, ‘Cell Fusion through Slime Mould Network Dynamics’, *Journal of The Royal Society Interface*, 19 (2022) <<https://doi.org/10.1098/rsif.2022.0054>>.

6 An overview of the characteristics and functions of model organisms, as well as the forms of social organization of research they generate, can be found in Rachel A. Ankeny and Sabina Leonelli, *Model Organisms* (Cambridge: Cambridge University Press, 2021) <<https://doi.org/10.1017/9781108593014>>.

On the next day I saw that the oat flakes were spanned with a network of protoplasmic tubes. The tubes looked like roads. 'What if we cut a piece of filter paper in the shape of some island and place oat flakes where cities are? Will the protoplasmic network match the existing roads?', I thought. There is only one way to find out. I have chosen the Isle of Wight as my first 'Physarum-land'. Results were intriguing yet inconclusive. Some roads were matched by the slime mould, others not. 'Minor roads are too messy. Let us try to imitate UK motorways,' I thought. First experiments showed that I hit a gold mine. I placed oat flakes in major urban areas of the United Kingdom and inoculated the slime mould in London. The slime mould grew the motorways in a couple of days. The match was almost perfect.⁷

In the following sections I discuss certain artistic and scientific experiments that engage *Physarum* as a model for human-made transportation systems or for collective human behaviours, and focus on how they conceptualize the relations between the slimy and the human. I investigate how these are mediated via different patterns of movement and network creation. In the first section, I discuss the properties of the slime mould that make for its weird appeal and openness to interdisciplinary applications. I then introduce Tim Ingold's typology of lines, which will serve as a means of analysis of chosen *Physarum* network experiments. Finally, I compare two types of experiments and trace how they draw their connections between the human and the slime.

BLACK BOX

Physarum polycephalum belongs to a large and diverse group of slime moulds: eukaryotic organisms that resist classification as either fungi, plants, or animals. They have been assigned to the kingdom of Protists, created to accommodate a variety of organisms that taxonomists could not fit anywhere else, and to the phylum of Myxomycetes.⁸ *Physarum* lives on forest floors in most parts of the world, feeding on bacteria, fungi spores, and decaying plant matter. At a certain point of its life

7 Andrew Adamatzky, 'Preface', in *Bioevaluation of World Transport Networks*, ed. by Andrew Adamatzky (Singapore: World Scientific, 2012), pp. v-vi (p. v) <<https://doi.org/10.1142/8482>>.

8 See *Myxomycetes: Biology, Systematics, Biogeography, and Ecology*, ed. by Carlos Rojas and Steven L. Stephenson (London: Elsevier, 2017).

cycle it forms a giant cell called a *plasmodium*, which is an aggregate of single-celled amoebae that can extend over tens of centimetres and contains millions of nuclei. When food sources are abundant it grows and moves at a relatively fast rate: its mass can double every few hours and it moves with the speed of approximately one centimetre per hour.

Even though *plasmodium* has a very basic internal structure, it forms a network of protoplasmic tubes that create an efficient system for transportation of nutrients within the cell. It is capable of simple forms of learning, such as habituation,⁹ and anticipates regularly occurring stimuli. The biophysical mechanisms behind these processes remain largely unknown, since at the molecular level the slime mould becomes an unstable and thus unwieldy research subject, due to its large number of nuclei and fast growth rate. Therefore, researchers so far have mostly focused on behavioural experiments, while the relations between behaviour and its underlying molecular mechanisms remain obscure. The way *Physarum* transforms environmental inputs into behavioural outputs is not controllable but is predictable. Arguably, in network recreation experiments it plays a role similar to a cybernetic black box. This resonates with Alexander Galloway's observations on invisibility as an anarchist political strategy and on the emergence of a new kind of opacity that is not a form of subversion but a function of a social system in which politics is replaced by management, and which conceives of biological, physical, and social behaviour as programmed and programmable.¹⁰ Galloway notes that 'the behaviourist subject is a black-boxed subject'¹¹ — that is, it is not necessary to understand its internal workings to be able to manipulate it. Therefore, 'it is no longer a question of illuminating the black box by decoding it, but rather that of functionalizing the black box by programming it.'¹²

9 Manon Ternois and others, 'Slime Molds Response to Carbon Nanotubes Exposure: From Internalization to Behavior', *Nanotoxicology*, 15.4 (2021), pp. 511–26 <<https://doi.org/10.1080/17435390.2021.1894615>>; Aurèle Boussard and others, 'Adaptive Behaviour and Learning in Slime Moulds: The Role of Oscillations', *Philosophical Transactions of the Royal Society B*, 376 (2021) <<https://doi.org/10.1098/rstb.2019.0757>>.

10 Alexander Galloway, "Black Box, Black Bloc", lecture delivered at the New School, New York City, 12 April 2010 <http://cultureandcommunication.org/galloway/pdf/Galloway_Black_Box_Black_Bloc.pdf> [accessed 25 March 2024].

11 Ibid.

12 Ibid.

The formation of plasmodium happens through aggregation of single-celled amoebae and is used as a model in studies of emergence and self-organization.¹³ Its internal structure is the product of a complex oscillatory system and metamorphoses at different stages of its movement under the influence of external factors, such as attractants and repellents encountered in its environment.¹⁴ Its shape transforms in the process of foraging and transporting nutrients, at a certain point contracting into a clear-cut web of tubes connecting food sources. There is ongoing research on slime mould's internal mechanisms,¹⁵ but in the network experiments discussed below it is treated as a black box, which reveals more about the pervasiveness of the idea of the social as a cybernetic system than about the slime mould itself.

While the black box metaphor is meant to capture the mechanistic aspects of *Physarum*'s behaviour, it does not exhaust its meanings and effects on the observer. The patterns and fluctuations of *Physarum*'s movements cannot be discerned with the naked eye, but are easily captured by means of time-lapse photography. The slime mould operates in a temporality adjacent to our own; it is just slightly too slow for its movements to be perceptible in real time by a human eye, but fast enough to surprise us with sudden expansions or attempts to escape from its Petri dish. It leaves us with the uncanny feeling that it only moves when we look the other way. It exists in the sphere just beyond our intuitive grasp, which David Roden postulates as the object of a dark phenomenology: '[a] feature of conscious experience is intuition-transcendent or "dark" if it confers no explicit or implicit understanding of its nature on the experienter.'¹⁶ Even though it can-

13 Bernd Meyer, Cedrick Ansoorge, and Toshiyoku Nakagaki, 'The Role of Noise in Self-Organized Decision Making by the True Slime Mold *Physarum polycephalum*', *PLoS ONE*, 12.3 (2017) <<https://doi.org/10.1371/journal.pone.0172933>>; Philipp Fleig and others, 'Emergence of Behaviour in a Self-Organized Living Matter Network', *eLife*, published online 21 January 2022 <<https://doi.org/10.7554/eLife.62863>>.

14 Boussard and others, 'Adaptive Behaviour'.

15 See, for example, Richard Mayne, Andrew Adamatzky, and Jeff Jones, 'On the Role of the Plasmodial Cytoskeleton in Facilitating Intelligent Behavior in Slime Mold *Physarum polycephalum*', *Communicative and Integrative Biology*, 8.4 (2015) <<https://doi.org/10.1080/19420889.2015.1059007>>.

16 David Roden, 'Nature's Dark Domain: An Argument for a Naturalized Phenomenology', in *Phenomenology and Naturalism: Examining the Relationship Between Human Experience and Nature*, ed. by Havi Carel and Darian Meacham, special issue of *Royal*

not be directly made sense of, '[a] dark phenomenon could influence the dispositions, feelings or actions of the experiencer without improving her capacity to describe them. [...] Our access to the dark side would thus be as theoretically and technically mediated as our access to the humanly unobservable universe.'¹⁷ One of Roden's dark examples is time, as the thing that we perceive without being able to grasp; slime mould's slow movements could be one of the instantiations of a phenomenon to which we only have mediated access due to its peculiar temporal characteristics, but so would be the internal mechanisms of slime mould's behaviour.

Slime mould's movements are perceptible only when mediated by time-lapse photography (or registered on video); the gaps between the snapshots are cut out, the representation of slime mould's movement is assembled from them and leaves out most of its activity. However, the human eye can perceive its shape at all times; its changes escape us not because they are invisible, but because they are too fine-grained for us to grasp. This constitutes another area of obscurity; the time-lapse is a technique of modulating the movements of *Physarum* (by setting up different snapshot intervals, different images are obtained) as much as representing them. It captures the fluctuations of the slime mould's internal cytoplasmic streams and reveals the stunning diversity of its morphology, inviting a human observer to interpret these movements as moments of hesitation, grasping, climbing, waving, pulsating, and forming different types of meshes. The time-lapse renders the slime mould alive and capable of making its own decisions, providing a fertile ground for scientific and artistic investigations into the non-human and distributed nature of cognition, intelligence, and emergent behaviour.

THREADS AND TRACES

Physarum's ability to create efficient nutrient transportation systems by finding the shortest path between food sources has been used in a number of experiments that have employed it to model different types of human-made networks. The first and most famous of these

Institute of Philosophy Supplement, 72 (2013), pp. 169–88 (p. 173) <<https://doi.org/10.1017/S135824611300009X>>.

17 Ibid.

were performed by Toshiyoku Nakagaki and his team at Hokkaido University. In 2000, they discovered that the slime mould could find the shortest way out of a maze, and in 2010 they demonstrated that it could recreate the suburban railway network around Tokyo with stunning precision.¹⁸ In both cases the time-lapses show a wave-like expansion of plasmodium covering a plane, followed by a contraction into a network of protoplasmic tubes. In the Tokyo experiment, suburban towns are represented by oat flakes located on a Petri dish covered by agar gel — these are given in advance, while *Physarum*'s task is to connect them in the most efficient way. The oat flakes constitute nodes in the network formed by *Physarum*'s tubes. Even though this and other similar experiments are usually claimed to recreate 'roads', 'railways', or 'routes', what they do is recreate the particular elements of modern maps that are reducible to networks.

However, before they are rendered as connections between points on a surface and abstracted into networks, *Physarum* tubes are just lines that emerge from its bodily movement, and it seems necessary to examine their qualities as lines before analysing the practices of network modelling in which they are involved. Tim Ingold proposes a typology of lines that consists of two basic classes: threads and traces. 'A thread is a filament of some kind, which may be entangled with other threads or suspended between points in three-dimensional space.'¹⁹ A fungal mycelium or the synapses of a nervous system fall into this category. A trace, in turn, is 'any enduring mark left in or on a solid surface by a continuous movement.'²⁰ Ingold also mentions ghostly lines, such as the ones that we imagine connect stars into constellations: 'lines of this sort may of course appear on maps and charts as traces drawn with pen and ink, using a ruler and compass. But they have no physical counterpart in the world that is represented on these maps.'²¹

18 Toshiyoku Nakagaki, Hiroyasu Yamada, and Ágota Tóth, 'Maze-Solving by an Amoeboid Organism', *Nature*, 407 (2000) <<https://doi.org/10.1038/35035159>>; Atsushi Tero and others, 'Rules for Biologically Inspired Adaptive Network Design', *Science*, 327 (2010), pp. 439–42 <<https://doi.org/10.1126/science.1177894>>.

19 Tim Ingold, *Lines: A Brief History* (New York: Routledge, 2007), p. 41 <<https://doi.org/10.4324/9780203961155>>.

20 *Ibid.*, p. 42.

21 *Ibid.*, p. 49. The fourth type of line, which features less prominently in his taxonomy and which does not interest me here, comprises cuts, cracks, and creases.

Ghostly lines are imagined but may have real and tangible effects, which I will discuss in the following sections.

According to Ingold, 'It is through the transformation of threads into traces, [...] that surfaces are brought into being. And conversely, it is through the transformation of traces into threads that surfaces are dissolved.'²² It follows from Ingold's argument that relations between lines and surfaces are determined by perspective; a thread enables orientation in a three-dimensional space, while a trace is made on a two-dimensional surface and is visible from a vantage point above that surface. Ingold uses the example of a maze as an illustration of this difference, referring, among other examples, to the labyrinth in which Theseus found his way thanks to Ariadne's thread, the Chukchee representations of the world of the dead that is also an underground maze, and the protective patterns drawn by women in Tamil Nadu on the thresholds of houses and temples, called *kampi kōlam*. In his polemic with Alfred Gell's claim that mazes are apotropaic patterns used for protection against evil forces, Ingold proposes another explanation of the maze, pointing out that Gell's argument 'assumes from the outset a kind of "demon's eye view" — an aerial perspective from which the overall layout of the maze may be surveyed and represented in a pattern-like form.'²³ The evil spirit is confronted with a riddle, which is supposed to stop it from entering the protected space. Contra Gell, Ingold argues that

[t]he entrance to the maze marks the point not at which [the traveller] touches down upon the surface, but at which he goes underground. Now as an interface between earth and air, the ground is a kind of surface that is visible from above, but not from below. It does not have another side. Thus at the very moment of going underground, of entering the labyrinth, the surface itself disappears from sight. [...] Thenceforth — and quite unlike Gell's demon which, caught in the contemplation of an apotropaic pattern, is glued to a surface — the ghostly traveller finds himself in a world without any surface at all. Every path is now a thread rather than a trace.²⁴

22 Ibid., p. 52.

23 Ibid., p. 56.

24 Ibid.

Ingold suggests that the function of mazes is to catch stray wanderers inside rather than present them with a riddle:

Rather than ambushing demons with an insoluble speculative conundrum, as Gell suggests, and causing them to get stuck in their attempts to figure out from the completed pattern the principles of its construction, the *kampi kōlam* more likely exercises its protective functions by catching them in the labyrinth, from which they can no more escape than ghosts in the world of the dead.²⁵

Both Gell's and Ingold's claims are of course highly speculative, but they illustrate a productive tension between the notions of the maze as a two-dimensional pattern and a three-dimensional space of wandering and getting lost, which characterizes the *Physarum* maze experiment as well. Its body is coextensive with its paths, which means its tubes can be characterized as both threads and traces: threads that transport nutrients in three-dimensional space, and traces on the two-dimensional surface of the agar gel. In Nakagaki's experiment, the slime mould enters the labyrinth and, after wandering along its paths, creates the shortest connection between the oat flakes located at its two entrances. The time-lapse allows us to observe it from 'the demon's eye view' and turn the tactile process of wandering and exploration into an intellectual puzzle.

Ingold's argument is built on the juxtaposition between the image of a maze drawn on a surface and the actual maze that requires a descent under the surface. It could be argued, though, that any maze is simultaneously both of these things. This is quite apparent when the slime mould gets caught in the maze but manages to escape by weaving a thread that is at the same time the solution to the 'speculative conundrum', a pattern visible from above. *Physarum's* morphology requires some surface for it to crawl, just as Ingold's underground traveller has to walk on something; however, those surfaces do not constitute geometrical planes on which patterns can be drawn. Such a surface exists and is visible only from one side; from the other, the traces dissolve into a three-dimensional tangle of threads.

25 Ibid., p. 57.

Ingold's aim is to uncover the material history of lines and the gradual process of their geometrical abstraction. Just as 'surfaces are dissolved through the transformation of traces into threads', threads in turn can be weaved into surfaces. However, Ingold distinguishes two types of surfaces: those woven from threads and those created by connecting points into geometrical shapes; the former material and textured, the latter smooth and abstract. As he writes, 'Lines that join dots mark the outlines of a mosaic of shapes. Such lines are not only drawn on a surface; they actually *define* that surface as a geometrical plane.'²⁶ Only after a thread is transformed into a trace on a surface can it be abstracted into a geometrical pattern. The Tokyo railway network experiment performs an analogical task by transforming the agar jelly in a Petri dish into an abstract geometrical surface on which a map can be drawn. Thus we arrive at another important distinction which Ingold takes from Paul Klee: between active and static lines. For Klee, lines that are traces of a physical gesture are active and 'go for a walk', as opposed to 'static' lines that connect predetermined spots:

Another kind of line, however, is in a hurry. It wants to get from one location to another, and then to another, but has little time to do so. The appearance of this line, says Klee, is 'more like a series of appointments than a walk'. It goes from point to point, in sequence, as quickly as possible, and in principle in no time at all, for every successive destination is already fixed prior to setting out, and each segment of the line is pre-determined by the points it connects. [...] If the former takes us on a journey that has no obvious beginning or end, the latter presents us with an array of interconnected destinations that can, as on a route-map, be viewed all at once.²⁷

According to Ingold, this transformation of the line from a trace on a surface to an assemblage of abstract points is characteristic of modernity:

Once the trace of a continuous gesture, the line has been fragmented — under the sway of modernity — into a succession of points or dots. This fragmentation [...] has taken place in the related fields of *travel*, where wayfaring is replaced by destination-oriented transport, *mapping*, where the drawn

26 Ibid., emphasis in the original.

27 Ibid., p. 73.

sketch is replaced by the route-plan, and *textuality*, where storytelling is replaced by the pre-composed plot. It has also transformed our understanding of *place*: once a knot tied from multiple and interlaced strands of movement and growth, it now figures as a node in a static network of connectors.²⁸

The fragmentation of lines replaces wayfaring with transportation — while wayfaring is for Ingold a form of inhabiting the world and weaving it from threads (lives, paths, stories), transport is a function of the imperial occupation of space. The lines that form the tissue of the habitable world are tangled and irregular, in contrast to the straight lines imposed by empires:

[I]n the course of history, however, imperial powers have sought to occupy the inhabited world, throwing a network of connections across what appears, in their eyes, to be not a tissue of trails but a blank surface. These connections are lines of occupation. They facilitate the outward passage of personnel and equipment to sites of settlement and extraction, and the return of the riches drawn therefrom. Unlike paths formed through the practices of wayfaring, such lines are surveyed and built in advance of the traffic that comes to pass up and down them. They are typically straight and regular, and intersect only at nodal points of power.²⁹

What to the wayfarer appears as a world weaved from crisscrossing threads is, in the imperial optics, a blank surface, or what the European lawyers defined as *terra nullius*, waiting for the imposition of a network of connections that will make it legible and governable by the empire.

Ingold's analysis shows that the word *network* is itself a homonym, meaning both a system of connections between nodes and a web of entangled threads, which are products of two different modes of movement and being in space: one based on the production of a surface, the other on its dissolution; one occupying a single viewpoint situated above the surface, the other taking on a wayfarer's perspective. The origin of the word *network* itself comes from fishing nets — tools for catching things, that is, performing a function analogical to Ingold's

28 Ibid., p. 75, emphases in the original.

29 Ibid., p. 81.

mazes. The threads and nodes of such a net have no meaning themselves, since what matters is the catch. Networks in the sense of systems of connections have the opposite function of leaving out all that is not part of the network. In *Physarum* network experiments, the lines drawn by the slime mould are simultaneously three-dimensional threads and two-dimensional traces, depending on perspective: from the slime mould's perspective, they are products of wayfaring and subsequently getting caught in a pattern of oats; from the researcher's perspective, they recreate imperial lines of occupation and extraction. Since they are given the nodes of the network, *Physarum* lines tend towards fragmentation, but after connecting the nodes they remain alive and keep moving, never exactly repeating the same pattern.

SLIME CARTOGRAPHIES

Nakagaki's widely publicized experiments spawned a number of similar attempts at recreating human-made transportation systems with the help of *Physarum*. One of the most prolific experimenters has been Andrew Adamatzky, head of the Unconventional Computing Laboratory at the University of the West of England in Bristol, who has engaged the slime mould in a wide variety of enterprises, from constructing Boolean logic gates to creating a biological microchip.³⁰ Adamatzky has cooperated with artists and urbanists in a number of interdisciplinary projects that have resulted in a large corpus of publications as well as exhibitions and art projects exploring *Physarum*'s uncanny abilities.³¹ The projects that interest me here investigate analogies between human and slime mould networks by means of recreating large-scale transportation systems, most of which have been documented in a volume entitled *Bioevaluation of World Transport Networks*.³²

30 See Andrew Adamatzky, *Physarum Machines: Computers from Slime Mould* (Singapore: World Scientific, 2010) <<https://doi.org/10.1142/7968>>; and *Advances in Physarum Machines: Sensing and Computing with Slime Mould*, ed. by Andrew Adamatzky (Cham, CH: Springer, 2016).

31 Andrew Adamatzky and others, 'On Creativity of Slime Mould', *International Journal of General Systems*, 42.5 (2013), pp. 441–57 <<https://doi.org/10.1080/03081079.2013.776206>>.

32 See *Bioevaluation of World Transport Networks*, ed. by Andrew Adamatzky (Singapore: World Scientific, 2012) <<https://doi.org/10.1142/8482>>.

Adamatzky's first success in the faithful recreation of British motorways with *Physarum* prompted him to perform a large number of similar experiments aiming to 'uncover analogies between biological and man-made [*sic*] transport networks'.³³ *Physarum* very efficiently approximates the lines of imperial occupation described by Ingold, because they too are designed to connect population centres via the shortest possible paths. The slime mould is placed at the centre of a system of political and spatial domination, given the points at which resources can be extracted, and faithfully recreates the transportation network that connects the nodes in the most efficient way. What is left out from the descriptions of these experiments is the fact that the capture of a network pattern is a temporal state, after which the slime mould continues to explore the Petri dish to create new patterns, which with time become more and more dense and tangled. Adamatzky's experiments followed the slime mould until the point at which all oats were connected, presenting this particular moment as an overall result, and imposing on the slime mould their own teleology. All experiments were repeated several times and the results were represented as graphs that captured the average shape of *Physarum* networks; the transformation of threads into traces was followed by the transformation of traces into what Ingold calls 'ghostly lines', by further straightening them out.

Ostensibly, the aim of the experiments was the 'bio-optimisation' of global transport networks by *Physarum*. The results were presented as numbered 'findings'. The experiments not only aspired to measure the precision with which *Physarum* can imitate modern transportation networks and to compare their efficiency, but also explored hypothetical catastrophic scenarios such as nuclear disasters. Using repellents such as sodium chloride to disrupt slime mould networks, they tested the networks' resilience and modelled their possible reorganization. For example, 'Finding 83' refers to a possible scenario of chemical or nuclear pollution in Malaysia and its impact on the transportation system:

If the epicentre of contamination is located in Kuantan and the speed of propagating contamination is about 100 miles per 24h, transport functionality will be significantly diminished in X14, X3 and X63 roads; a substantial increase in traffic will be

33 Ibid., p. 8.

observed between the Kota Bahru and the Alor Star, Sungai Petani and Kulim areas; a significant increase in migration and economic activity would also be observed in Kedah and north Perak and Kelantan states.³⁴

The predictive value of Finding 83 is impossible to estimate, but the narrative is compelling because it invokes a popular genre of apocalyptic fiction. Even though the ostensible aim of the book is to uncover analogies between large-scale transportation systems and *Physarum* networks, the experiments cross the boundaries between art and science and engage in speculation on the catastrophic scenarios built into the imperial lines of occupation. Some experiments model hypothetical disasters such as the malfunction of nuclear facilities, while other scenarios include the simulation of drug trafficking routes in Mexico or the colonization of Germany. That the apocalyptic storytelling is an important, albeit unstated, aim of the experiments is reflected in some of the chapter titles, such as ‘Germany colonised’ or ‘Physarum narcotrafficum’. Other experiments conducted by Adamatzky have speculated on possible human migration routes between Mexico and the USA,³⁵ provided scenarios of future world colonization beginning in China,³⁶ and projected the colonization of the Moon.³⁷ All of these use *Physarum* for modelling what Ingold understands as lines of imperial occupation and control.

The slime mould is used as a model for the effective regeneration and recreation of connectivity after a network is disrupted, but at the same time the procedure is one of colonization, which here denotes both the colonization of an agar plate by the slime mould and the colonization processes that resulted in the emergence of global transportation systems. *Physarum* colonizes the Petri dish by covering it with its slimy body and imposing on it a map of protoplasmic

34 Ibid., p. 192.

35 Andrew Adamatzky, and Genaro J. Martinez, ‘Bio-Imitation of Mexican Migration Routes to the USA with Slime Mould on 3D Terrains’, *Journal of Bionic Engineering*, 10 (2013), pp. 242–50 <[https://doi.org/10.1016/S1672-6529\(13\)60220-6](https://doi.org/10.1016/S1672-6529(13)60220-6)>.

36 Andrew Adamatzky, ‘The World’s Colonisation and Trade Routes Formation as Imitated by Slime Mould’, *International Journal of Bifurcation and Chaos*, 22.8 (2012) <<https://doi.org/10.1142/S0218127412300285>>.

37 Andrew Adamatzky and others, ‘Slime Mould Analogue Models of Space Exploration and Planet Colonisation’, *Journal of the British Interplanetary Society*, 67 (2014), pp. 290–304.

tubes, thus turning it into a geometrical plane. By recreating large-scale transportation systems with *Physarum*, Adamatzky's experiments at the same time retell the history of imperial expansion that led to their creation.

The properties of *Physarum* graphs — such as average edge length, average shortest path, diameter, and cohesion — are compared with the actual transportation networks that were the basis for the experiments. The final chapter of *Bioevaluation of World Transport Networks*, titled 'Bio-rationality of Motorways', summarizes the analogies found between motorways and *Physarum* networks. The fact that the comparison is made between graphs — one representing the actual transportation network and the other its recreation by *Physarum* — can be missed, because the narrative that accompanies and explicates them conflates the graphs with *Physarum* itself. The analogy becomes lost and enters the realm of fiction when the authors suggest that the comparison is not between two graphs based on a particular map, but between slime mould's behaviour and socio-political phenomena, such as the colonization of particular countries, the building of roads, or the smuggling of drugs. In the narratives of Adamatzky and his collaborators, *Physarum* metamorphoses from a biomechanical device that can effectively connect oat flakes on an agar plate into an entity that roams the earth, connecting population centres with its protoplasmic tubes and extracting their resources, as reflected in paper titles such as 'Road Planning with Slime Mould: If *Physarum* Built Motorways It Would Route M6/M74 through Newcastle'.³⁸

Staying within the narrative style of *Physarum* experiments, one could say that the slime mould has a taste for dystopia, in which the flows of human masses and the flows of capital are treated as emergent phenomena that can be modelled, predicted, and optimized but not problematized in any way. *Physarum* confers onto them the black box logic that makes the experiments possible in the first place; the scope of its networks and the processes they are meant to represent are limited by what is already given. The network experiments are elaborately

38 Andrew Adamatzky and Jeff Jones, 'Road Planning with Slime Mould: If *Physarum* Built Motorways It Would Route M6/M74 through Newcastle', *International Journal of Bifurcation and Chaos*, 20.10 (2010), pp. 3065–84 <<https://doi.org/10.1142/S0218127410027568>>.

staged to imitate the process of colonization; agar plates provide a *terra nullius*, an uninhabited space for expansion,³⁹ while the nodes of the network given in advance are literally resources ready for extraction. The experiments result in the emergence of a system of ghostly lines that approximate cellular expansion and historical colonization. The scale of the maps is never mentioned because the scenarios have no predictive value; rather, they are an exercise in imaginary worldmaking. They serve to reproduce a map of the colonized world, staging the act of imperial occupation through the capture of *Physarum*'s threads and their transformation into straight lines and abstract networks.

LIVED ABSTRACTION

The performances collectively entitled *Being Slime Mould*, alongside other projects by the London-based artist Heather Barnett, operate within the same conceptual coordinates as the network experiments discussed above, but here the relations between threads and traces, slime and human behaviours, and maps and movements are in various ways shifted, reverted, or displaced.⁴⁰ Barnett invites participants in her experiments to form a collective body that acts according to the same rules as the slime mould; for this purpose *Physarum*'s behaviour is reduced to a simple algorithm that the participants are asked to follow.⁴¹ The experiment is a comparative procedure in which human behaviour approximates the slime mould's by means of embodied practice. The rules of movement and aggregation are given in advance, and by following them participants create patterns of connection that can be abstracted into networks. However, this is not the point of

39 Such an argument, in the context of microbiology in general, is made in Georgina Tuari Stewart and others, 'Colonization of All Forms', *Educational Philosophy and Theory*, 56.11 (2024), pp. 1039–43 (p. 1040) <<https://doi.org/10.1080/00131857.2022.2040482>>.

40 For an overview of Barnett's artistic engagement with *Physarum*, see Heather Barnett, 'Many-Headed: Co-Creating with the Collective', in *Slime Mould in Arts and Architecture*, ed. by Andrew Adamatzky (Gistrup, DK: River Publishers, 2019), pp. 13–37 <<https://doi.org/10.1201/9781003339540-3>>.

41 The algorithm imitates the process of aggregation of slime mould amoebae and consists of three or four steps, such as: 1. Move around, maintaining equal distance from others; 2. When you find a resource, stop; 3. When you bump into a person connected to a resource, make a link; 4. If you bump into a person connected to another person, make a link.

the performance. Rather, its aim is to stage the process of emergence of a collective body and to provide the participants with a different experience of collectivity, one that emerges from bodily movements, unmediated by symbolic communication. The results are connection patterns but also ethnographic observations, as every group behaves differently, making different use of their bodies and interpreting the rules in different ways. The collective performances allow the artist to investigate how different human bodies relate to other bodies and to space. As Barnett's title suggests, *Being Slime Mould* is about approximating the slime mould's perspective and exploring the environment as a slime mould would — its form of engagement is that of the embodied perception of a wayfarer rather than of the totalizing imperial eye. The rules of behaviour are abstracted from the observation of slime mould's movement and are analogous to cellular automata, but their implementation creates a space for exploring embodied connections and collective movement. At the moment when the algorithm is implemented by humans in a three-dimensional space, it becomes a method of inquiry into this space and the threads and connections that sustain it.

The process of embodied inquiry can then be abstracted back into a two-dimensional pattern of lines, as in the project *Swarm/Cell/City* (2017), a cooperation between Barnett and Art Laboratory Berlin, which aimed to explore 'collective communication, cooperation and navigation at different scales [...] in slime mould and in humans' by means of 'participatory art and performance practices'.⁴² The experiment was designed to investigate 'the creative potential for bio/social models' and to create a collective 'system of enquiry'.⁴³ The human slime mould evolved from a performance into a method of collective research: Barnett's experiment provides an opportunity for self-inquiry that starts with wayfaring rather than occupation. The participants in the *Swarm/Cell/City* project explored a neighbourhood of Berlin's Pankow district by leaving and tracking traces, weaving a surface from the threads of individual movements and creating maps that emerged

42 'NONHUMAN AGENTS: Swarm | Cell | City', artlaboratory-berlin.org, n.d. <<https://artlaboratory-berlin.org/events/swarm-cell-city/>> [accessed 26 July 2024].

43 Ibid.

in the process of collective exploration of urban space. This collective wandering was tracked and transferred onto a map, producing abstract images that captured the contingencies and convergences between individual lines, revealing a pattern of collective movement. As in the network experiments, the wayfaring experience was transformed into a pattern of traces on a two-dimensional map, but there were no pre-given nodes of the network and no imperative to find the shortest paths between them. The emerging image was a projection of the tangled threads onto a two-dimensional plane, consisting of lines literally going for a walk.

In important ways, Barnett's performances are the antithesis of Adamatzky's experiments: the slime mould is used to model human collective wayfaring instead of modern transportation; the lines of movement are continuous and not broken; the lines that emerge are threads and not traces; and the patterns of aggregation are investigated in their uniqueness and not in the average. Nonetheless, they are haunted by the abstract body of the slime mould and the ghostly lines that are drawn from it. The slime mould appears to have a double body — the material blob and the abstract network — and to oscillate continuously between wayfaring and transporting, creating threads and leaving traces, meandering and straightening its lines to find the shortest path between the oats, and between getting caught up in a three-dimensional space and revealing patterns on a surface. The attempts at approximating human-made and *Physarum* lines and networks produce effects that go far beyond their stated aims: as has been demonstrated above, the comparison between slime mould and humans is made possible through a multilayered process of abstracting their behaviour into networks; at the same time, the lines that those networks are made of are revealed to be complex processes.

COMPARING THE INCOMMENSURABLE

In a paper based on sociological research among biologists working with *Physarum*'s cognitive capacities, Jacqueline Dalziell asks: 'Could it be that within the microbiological we might find humanity's self-inquiry, a form of self-reflection yet one whose refracted involvements

do not return us to anthropocentrism in any straightforward way?'.⁴⁴ This question leads me to Eduardo Viveiros de Castro's account of Amerindian perspectivism, which assumes that all living entities are persons and thus occupy a point of view. Those points of view are often as incommensurable as the bodies they are located in, but they nonetheless have to be imagined as inhabitable if any form of communication and understanding is to be possible. The method for doing so, according to de Castro, would be a 'controlled equivocation', taking the incommensurability as its premise and vantage point. 'Only the incommensurate is worth comparing',⁴⁵ claims de Castro; the experiments described in this paper are based on a similar premise, as the homonymy between webs and networks, as well as the interchange between lines as threads and lines as traces, constitutes their operating mechanism. The slime mould's two bodies converge in lines and networks that oscillate between materiality and abstraction in a process analogous to de Castro's controlled equivocation, in which both the slimy and the human are mediated by a tangle of material and abstract lines. De Castro invokes Patrice Maniglier, claiming that any anthropology worth its name 'returns to us an image in which we are unrecognizable to ourselves'.⁴⁶ Recreating human networks with *Physarum* achieves a similar effect: far from anthropomorphizing the slime mould, it renders the human slimy, modelling its patterns of movement in a way that is at the same time material and abstract, and distinctively non-human.

44 Jacqueline Dalziell, 'Microbiology as Sociology: The Strange Sociality of Slime', in *What If Culture Was Nature All Along?*, ed. by Vicki Kirby (Edinburgh: Edinburgh University Press, 2017), pp. 153–78 (p. 154) <<https://doi.org/10.1515/9781474419307-010>>.

45 Eduardo Viveiros de Castro, *Cannibal Metaphysics: For a Post-Structuralist Anthropology* (Minneapolis: University of Minnesota Press, 2014), p. 90.

46 Ibid., p. 41. Quote from Patrice Maniglier, 'La Parenté des autres. À propos de Maurice Godelier', *Critique*, 701 (2005), pp. 758–74 <<https://doi.org/10.3917/criti.701.0758>>.

RESPONSE BY B CAMMINGA: BEWARE OF THE BLOB, OR WHEN IS THE SLIME MOULD A COLONIZER?

To better understand the *Physarum polycephalum*, also known as *slime mould*, I watched the 1958 ‘schlock’ sci-fi classic *The Blob*. The film not only marked a breakthrough for Steve McQueen but is often referenced in discussions of the single-celled organism as one of its few cinematic depictions. The accompanying theme tune, with its lyrics ‘Beware of The Blob, it creeps and leaps and glides and slides’, introduces the organism as a mischievous trickster (think *The Addams Family*, 1991). However, as the story unfolds, the audience is offered the image of a slowly metastasizing and all-consuming terror. In *The Blob*, humans are the oat flakes. We are the resource to be extracted. Turning up the fear with the much shorter tagline ‘Terror has no shape’, *The Blob* was remade in 1988. To my surprise, though, aside from *The Blob*, one or two short stories, and Philip K. Dick’s *Clans of the Alphane Moon* (1964), which features a telepathic slime mould named ‘Lord Running Clam’, the slime mould’s eerie vibe and alien-like qualities have not attracted as much attention from sci-fi writers and filmmakers as one might expect. Of course, there is the recent appearance of *Physarum* in the 2023 hit TV series *The Last of Us*. However, in the show, *Physarum* plays stunt double to the main character, Mycelium, and for the most part, the audience is unaware that one is substituting for the other.

Science fiction, then, has perhaps not yet fully tapped into the potential of *Physarum*; the 1958 film poster indeed billed the organism as ‘indescribable’. Yet, as Maria Dębińska’s chapter suggests, slime mould, or, more precisely, the narratives of slime mould experiments, have certainly leaned into the science fiction subgenre of ‘apocalyptic fiction’. As Dębińska explains: ‘Staying within the narrative style of *Physarum* experiments, one could say that the slime mould has a taste for dystopia.’

The narrative descriptions of experiments unmistakably portray slime mould as mysterious, otherworldly, and alien. One of the startling outcomes in Dębińska’s chapter is a difference in the narrative between slime mould modelling and modelling slime mould. When slime mould is modelled, as in the Andrew Adamatzky experiments,

it is imbued with nefarious intent: it is extractive, imperial, and almost single-mindedly colonialist. However, when humans model slime mould, as with Heather Barnett's artistic experiment, imperial imageries and colonial metaphors and descriptors are conspicuously absent. Instead, the focus is on connection, engagement, exploration, and embodied movement.

The desire to describe what the slime mould does in colonialist terms is a surprising difference in the models the chapter presents, revealing more about humans than about slime mould, as Dębińska makes clear. While the experiments may 'render the human slimy', perhaps they also accentuate the slimy or unpleasant propensities in humans themselves. Indeed, Noah Berlatsky argues that the 'colonial experience remains more tightly bound up with our political life and public culture than we sometimes like to think'.⁴⁷ In placing Adamatzky alongside Barnett, these 'exercise[s] in imaginary world making' reveal the limits of those worlds. Whether as dystopic projections onto experiments in modelling slime, or as engagements with slime as a harmless algorithmic model for experimental human connection, they reveal, to follow Berlatsky, 'the extent to which dreams of what we'll do remain captive to the things we've already done'.⁴⁸

47 Noah Berlatsky, 'Why Sci-Fi Keeps Imagining the Subjugation of White People', *The Atlantic*, 25 April 2014 <<https://www.theatlantic.com/entertainment/archive/2014/04/why-sci-fi-keeps-imagining-the-enslavement-of-white-people/361173/>> [accessed 14 April 2024].

48 Ibid.

Maria Dębińska, 'The Slime Mould's Many Bodies, or Modelling Networks with *Physarum polycephalum*', in *Breaking and Making Models*, ed. by Christoph F. E. Holzhey, Marietta Kesting, and Claudia Peppel, Cultural Inquiry, 33 (Berlin: ICI Berlin Press, 2025), pp. 109–30 <https://doi.org/10.37050/ci-33_04>

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