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**The Subjecthood of Slime Mould: modelling single-celled
intelligence through living systems art**

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The Subjecthood of Slime Mould:

modelling single-celled intelligence

through living systems art

Heather Barnett

A commentary and portfolio submitted in partial fulfilment of the requirements of the University of Westminster for the degree of Doctor of Philosophy by Published Work

November 2023

Abstract

This PhD by Published Work presents a body of artistic research created by Heather Barnett working with the slime mould, *Physarum polycephalum*, a single-celled amoeba employed as a model organism within a wide range of disciplinary domains. *The Physarum Experiments* is an ongoing multifaceted enquiry examining nonhuman subjecthood, producing outputs in the form of artworks, methods for co-enquiry, and critical texts. Selected published works, produced predominantly between 2015 and 2019, are discussed in the context of theories, histories, and cultural frameworks drawn from biology, art, and philosophy.

The behavioural characteristics of slime mould embody emergent unpredictability, which is visually and aesthetically engaging, and performative in its articulation of the *otherness* of the nonhuman. Metaphorically, this enables a rich language that alludes to the complex interweaving of systems that we share and co-constitute with other forms of life. In emphasising the role of the nonhuman as both a subject and co-creator, the work connects in practice what contemporary posthumanities scholars argue is urgently needed in response to the planetary crises currently faced, arguing for the expanded consideration of systems thinking (Bennett), environmental response-ability (Haraway), posthuman knowledge (Braidotti) and ecological attunement (Morton).

Within the thesis the slime mould is defined, not merely as an epistemic thing (Rheinberger) but, as a material, relational and behavioural model – a biological analogue which, through the creation of artworks and experiences, provides a means of accessing nonhuman imaginings and speculative subjectivities. Slime mould '*modelled*' in artistic contexts, it is argued, can help us attune to the character and capabilities of other forms of intelligent life and establish relational agency. Through the evidence provided within the portfolio and contextual commentary, the thesis argues that biological models employed in exploratory and interdisciplinary artistic enquiry can provide a vehicle through which we can re-evaluate anthropocentric subjectivities and expand interspecies epistemologies.

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Author's declaration

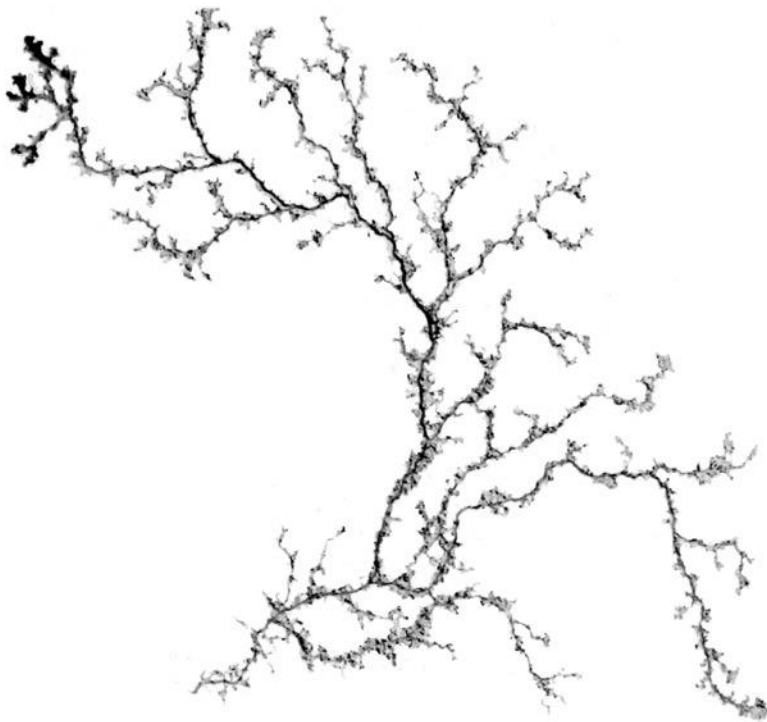
I declare that all the material contained in this thesis is my own work.

Heather Barnett

November 2023

Part A) Commentary on the Published Work

1. Introduction



The Physarum Experiments: Growth Studies #1 Amplification

1.1 Overview

Moving beyond humanist exceptionalism, subjectivity has to include the relational dependence on multiple non-humans and the planetary dimension as a whole. Transversality is the operational concept that helps to conceptualise the subject across multiple axes.

(Braidotti, 2019 : 40)

The slime mould, *Physarum polycephalum*, is a single-celled amoeba used as a model organism within a wide range of disciplinary contexts, including the study of network optimization, cellular motility, proto-cognition, and biochemical sensing. Fields of research include unconventional computing, biophysics, urban planning, philosophy, and art. The organism has no brain, no central nervous system, nor any sensory organs, yet can demonstrate surprisingly high levels of computation and perform tasks we normally associate with brain function, such as problem-solving, memory and learning. There are a great many human minds asking myriad questions of this many-headed organism.

Since 2009 the organism has been employed – as material, model, and metaphor – in an ongoing artistic enquiry, generating speculative artworks that reflect upon the interrelationships between human and nonhuman ontologies, and developing a set of methods to bring others into that mode of enquiry. This ongoing 'collaboration' with a single-celled intelligence has evolved along diverse yet interconnected trajectories, involving the making of films, sculptures, and collective experiments, grouped under the umbrella title of *The Physarum Experiments*. Using this body of interdisciplinary artistic research as a critical case study, the portfolio of published works and the written commentary present an investigation of species subjectivities, interspecies encounters, and experimental systems of co-enquiry.

Drawing on theories, histories and cultural frameworks from biology, art, and philosophy the commentary explores the subjecthood of slime mould through discussion of the artworks, encounters and experiences created (and co-created). It is argued that through exploratory and interdisciplinary enquiry, biological organisms employed within an artistic context can mediate ontological thinking and provide a vehicle through which we can re-

evaluate how we see ourselves and relate to co-companion species within our shared environment.

In using the published work as a case study to define terms and processes, the thesis builds a model which can be applied to artistic research co-constituted with other living systems. Whilst the organism under discussion here - slime mould - possesses unique traits and characteristics which are ontologically and epistemologically specific, the methods developed demonstrates wider applicability to other artist/ organism/ audience/ participant interactions.

1.2 Framing the Research

A set of provocations and guiding principles have been at the forefront of this enquiry, directing interspecies exploration in its making. The primary research questions driving the practice-based research are concerned with:

- How *artistic mediation* can engender the subjecthood of 'lower' organisms and foster *relational agency* through the production of artworks, experiences, and encounters that invite *interspecies speculation*.

Methodologically this question is examined through different theoretical lenses exploring:

- How interdisciplinary *experimental systems* can be constituted and nurtured to facilitate a pluriverse of *collective co-enquiry* and exemplify the principles of *emergence*.
- How a biological organism (the slime mould) can operate as an *epistemic thing* and a *boundary object* at the interface between *species subjectivities* (human and nonhuman) and between disciplinary *modes of enquiry* (art and science, philosophy and ecology).

Whilst the work began in 2009 and continues to this day - an iterative and evolving process of investigation into the conceptual and material properties of slime mould - the commentary focuses particularly on works produced between 2015 and 2019. During this period significant processes, methods and outputs were formulated which mediate species subjectivities. The thesis sets out new models for future relational interactions with

nonhuman subjects within my own artistic research and within the wider domain of what I define as *living systems art*, an empirical form of artistic research which embraces the complexity and multiplicity of the interrelations between organisms and their situated ecologies.

1.3 Methodologies of Interdisciplinary Enquiry

The work is situated within the cultural frame of 'art and science', specifically the domains of bioart and ecological art. By intersecting with, appropriating, and critiquing the tools of science, artistic practice within these interdisciplinary domains is often highly research orientated, and instrumental in developing hybrid methodologies which challenge established knowledge domains. The research presented triangulates between disciplinary methods, mindsets, and approaches from the fields of art, biology, and philosophy. It is at times, what I define as, *multidisciplinary* (bringing different disciplinary perspectives together), often *transdisciplinary* (engendering transference of insights across knowledge domains), and, frequently, *a-disciplinary* (purposefully operating without any disciplinary distinctions). For the sake of simplicity, I will refer mostly to *interdisciplinary* modes of working, where the merging of methods forms hybrid experimental tools and systems. The nature of the interdisciplinarity at play is fluid, fluctuating across the individual (and interconnected) strands of research. A persistent caveat is that all knowledge systems are contestable and mutable and should be open to appropriation and reconsideration from outside specialist domains (and from outside academia in the guise of public realm research). Within the methodological frameworks employed, thinking from the fields of biology and philosophy is brought into dialogue with the material and experiential modes of artistic enquiry, where imaginative speculation - what Donna Haraway refers to as *speculative fabulations* (1988, 2015, 2016) - challenges dominant hierarchies of disciplinary knowledge domains. Haraway uses the abbreviation *sf* to navigate between the realms of science fact and speculative fiction, both of which, she argues, are needed as a "sense of figuring" and as "a method of tracing" for the "cultivating of multispecies justice" (2016 : 3).

The ‘figuring’ presented in the published work comprises a body of rigorously researched, planned, and executed artworks, experiences, and events, complemented by a series of published peer-reviewed texts. A central tenet of the thesis is to define how methods employ an organism to *think with*, engaging a biological entity as a vehicle for empirical enquiry and practical philosophy. Thinking *with* slime mould in practical terms - observing and embodying nonhuman ontologies – involves enactment of key theories from the philosophy and history of science, as well as from contemporary posthumanities and ecophilosophy scholarship. The relationship between theory and practice is entwined as praxis.

These entanglements and encounters include exploratory and interdisciplinary methods employed within the artistic research through the lens of *process biology* (Nicholson and Dupré, 2018) *speculative realism* (Shaviro, 2014), *experience in art and in nature* (Dewey 1995, 2005; Manning and Massumi, 2014), and the *semiosphere of the Umwelt* (von Uexküll, 1992). The discussion references published works from *The Physarum Experiments* presented in the portfolio, most notably the material studies employing time-lapse photography, experimental methods used in public realm research and experiential embodied experiments, alongside key published texts. The narrative critically evaluates selected works in relation to the *experimental systems* (Rheinberger, 1997; Schwab, 2013) employed, designed to create the conditions for unexpected outcomes to *emerge* (Johnson, 2002).

As an historian of science, Rheinberger defines experimental systems as “vehicles for materialising questions” through an iterative, recurrent, and improvised process of enquiry, resulting in feedback loops where the systems “inextricably cogenerate the phenomena or material entities and the concepts they come to embody.” (Rheinberger, 1997 : 28). Rheinberger’s thinking about scientific experimental systems has been taken up by the domain of artistic research, most notably a collection of essays which “trace some links between experimentation and artistic practice—by comparing the laboratory and the studio, by focusing on material practice, by describing systems of creation, or by highlighting temporal or experiential dimensions.” (Schwab, 2013 : 6). The translation of thinking between disciplines - examining laboratory processes, the culture of research, and the tacit

dimensions of experimental epistemologies - is explored through a multitude of practices and positions, which I build on in relation to *The Physarum Experiments*.

The experimental systems developed in an interdisciplinary artistic context working with slime mould echo those found in scientific enquiry. The phenomenological and material properties of the organism cogenerated through a recursive dialogue between *explicit* and *tacit* knowledge, what polymath and philosopher of science Michael Polanyi defines as 'personal knowledge', the embodied knowledge held through experience, which cannot easily be told (2012 ; Polanyi and Sen, 2009). Within my own experimental system, knowledge is cogenerated by living material, environmental sculpting, and technological intervention, whereby the organism reveals itself through my stimuli. While patterns of behaviour can be predicted, the outcomes cannot be controlled, producing recurrently surprising results. As in the scientific context, the experimental system within an interdisciplinary artistic context evolves as "tinkered arrangements that are not set up for the purpose of repetitive operation but for the continuous reemergence of unexpected events" (Rheinberger, 1997 : 32).

While developing hybrid methods and approaches, all elements coalesce under the banner of practitioner-research which is iterative and cumulative, embedded in the making of artefacts and/or experiences, highly invested in communicating ideas and receiving feedback through evaluative processes (Candy and Edmonds, 2010). Addressing the 'multi-component' methodologies (Velonaki, 2012), where many elements work together but can be deconstructed and differentiated, the material investigations (and their resulting artworks) operate in combination with the modes of co-enquiry – the material, relational and behavioural aspects in dialogue with each other. For example, the 'practitioner frameworks' (Candy and Edmonds, 2010) developed in the studio, engaging the slime mould in the making of time-lapse studies, are transposed into participatory engagement through the invitation for others to create their own systems of enquiry. The understanding of the organism, and its inherent attributes and characteristics, is conveyed through the time-lapse studies as a form of visual storytelling inviting relational encounters. The combination of visual media, living organism and technological apparatuses create an *assemblage* of interconnected elements within the experimental system. The knowledge domains

operating within the system combine explicit knowledge (*about* the organism), tacit knowledge (*from* the organism) and conceptual speculation (*of* the organism), packaged up within a social learning experience.

1.4 Structure of the Commentary

As a practice-led enquiry, the published work presented in the portfolio provides an annotated visual journey through the two main sections of artistic research: material investigations (working directly with the organism) and systems of co-enquiry (working with others in experimental settings). The portfolio comprises film stills from a selection of time-lapse studies; print, digital media, and live artworks; documentation of experimental systems and technical apparatus; and documentation of co-enquiry research including workshops, situated actions, collective and embodied participatory experiments.

Throughout the portfolio selected excerpts from the published texts are juxtaposed, relative to the research presented. The full texts of these published writings are provided in the third section of the portfolio. To aid navigation much portfolio content is referenced from the main body of the commentary.

The interdisciplinary artistic research invites audiences and participants to become *attuned* to the subjective sensory world of an alien, yet relatable, organism. The methods of working are rhizomatic, iterative, and cumulative, building multi-layered knowledge through heightened awareness, encounter, and experience. Therefore, the navigational logic is similarly rhizomatic, thematically structured rather than strictly chronological, defining the different strands of research as they intersect and interact in a dynamic and networked way. The narrative should unfold in a 'slime mould-esque' way through the reading, as follows:

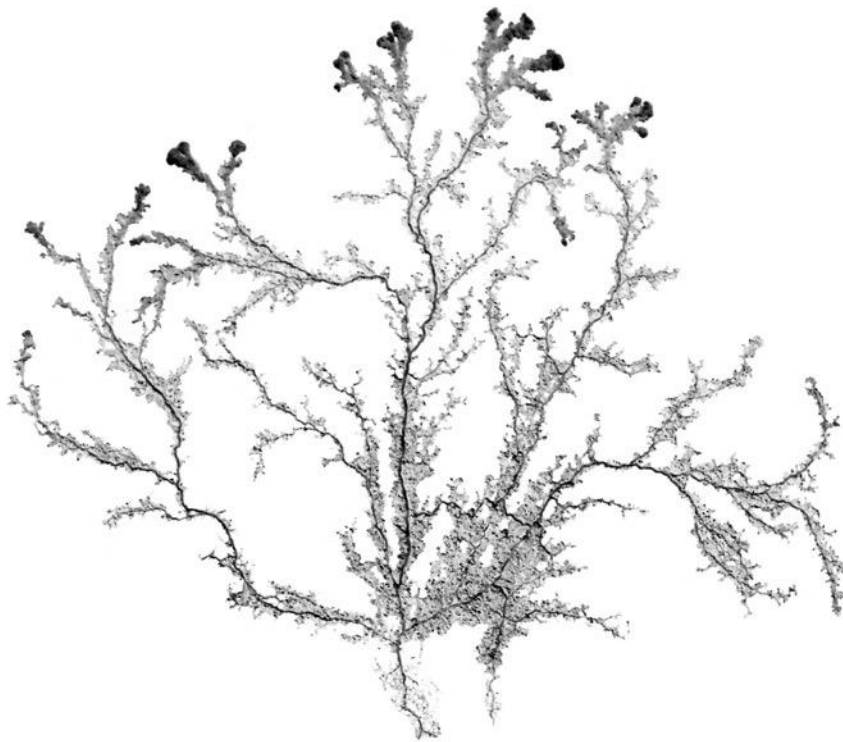
- The Contextual Review (Section 2) locates the work at an intersectional point between art, biology, and philosophy, placing the research within the cultural context of interdisciplinary visual art and participatory practices. The protagonist of the enquiry, the slime mould, is introduced in terms of its biological interest and its use as a model organism within different knowledge systems. Theoretical

frameworks integral to the creation of the work are introduced to critically contextualise the methods, intentions, and outputs. The Contextual Review sets the scene for *polycephalic* (many-headed) thinking.

- The Published Works (Section 3) are presented within two significant bodies of research. The first focuses on artistic research created through direct engagement with the organism as subject of study, artistic material, and living co-creator. The second body of work engages other humans in systems of co-enquiry through the design of workshops, collaborative exploration, and collective experimentation. Methods and frameworks developed through the multi-modal interdisciplinary enquiry are defined.
- The Conclusions (Section 4) articulate the knowledge generated through the research and examine the slime mould as a *boundary object* carrying *nomadic concepts*. New definitions of the *model organism* within artistic contexts are presented which embrace material, relational, and behavioural intra-actions.
- A short Afterword (Section 5) positions the research within current posthumanities and ecophilosophical discourse, arguing that the published works have been at the forefront of cultural activity connecting art, biology, and philosophy within a framework of multispecies justice and ecological thinking (and acting).

The backdrop to the research stems from twenty-first century environmental and planetary concerns, and how we best deal with the complexities and uncertainties of our time. Collectively the work, and the critical commentary, argues for the urgent need for inclusive, interdisciplinary, and integrative methods for bringing many heads together to collectively investigate other living intelligences and acknowledge their epistemic and ontological value.

2. Contextual Review



The Physarum Experiments: Growth Studies #2 Cooperation

2.1 Contextual Overview

Living systems are cognitive systems, and living as a process is a process of cognition. This statement is valid for all organisms, with or without a nervous system.

(Maturana and Varela, 1980)

The Physarum Experiments is an ongoing interdisciplinary enquiry created with a biological organism as artistic material, metaphorical model, and relational agent. The practice-based investigation has developed with a combination of artistic, scientific, and philosophical knowledges. The research is situated at the intersection of biological art (bioart) and ecological art (ecoart), where the observation of and intervention with living systems performs multifaceted roles. Within this cultural context, the 'living' functions both as a subject of enquiry and an artistic medium for material exploration. The work also employs social and participatory practices involving pedagogic and performative characteristics, inviting other people into cooperative and collaborative processes.

Much of the artistic research presented is concerned with the inherent properties of a particular biological organism and grounded in scientific literature and methodologies. Therefore, the biological characteristics of the slime mould are introduced, referencing key literature from the sciences. The ways in which this organism is *worked with* in artistic and other non-scientific realms of enquiry is also introduced. Such works, bridging interspecies encounters, often engage with related philosophical readings, drawing on discourses from the scholarship of posthumanities, new materialism, and ecophilosophy. Collectively, the biological, technological, and social build relational *experimental systems* (Rheinberger, 1997 ; Schwab, 2013) inviting one species to contemplate other ontological and epistemological *processes of life* (Nicholson and Dupré, 2018).

Such artistic research, which merges biological and social systems, and engages across scales and species, I define here as *living systems art*, a field of interdisciplinary artistic research which creates points of interconnection between biological, technological, and social behaviours, and which brings observed phenomena and speculative imaginings into dialogue. Through the portfolio and critical commentary, the unique conditions and

methodologies which define living systems art are set out, situated within a body of work produced with the slime mould, *Physarum polycephalum*. Here, the slime mould takes on a malleable role of medium, model, and relational subject.

2.2 Artistic Context

The work presented is located within the broad domain of ‘Art and Science’, a contemporary Western cultural movement which has built momentum since the 1950s in accordance with the advent of significant ‘biosociotechnological’ developments eliciting a creative response from the arts, such as the discovery of the structure of DNA in the 1950s and the expanded field of genetics (Anker & Nelkin, 2004), the growth of cybernetics and computer technology in the 1960s (Pearl, 2021), and the ethical implications of biotechnologies at the turn of the 21st Century (Kac, 2007). *The Physarum Experiments* is situated within this interdisciplinary field, traversing the cultural domains of the laboratory and the studio and, more specifically, connecting the interrelationships between ‘art and biology’, working with the fundamental processes of life.

2.2.1 Art and the Living

Emerging in the 1980s and ‘90s, biological art (bioart) is a field of contemporary artistic practice that involves working with biological materials, processes, and concepts. The term was first coined by artist Eduardo Kac¹ in 1997, in relation to his artwork *Time Capsule*, which “involved biological agency (as opposed to biological objecthood)” (Kac, 2007 : 164). Whilst there are differing definitions of bioart, it is generally considered not to be *about* biology or *inspired by* biology, but inherently *working with* fundamental biological processes and defined by technoscientific concerns and laboratory apparatuses within which life science research operates. Developed in “response to the cultural dislocations that are

¹ Eduardo Kac is considered a pioneer of bioart, best known for his 2000 piece, *GFP Bunny*, a genetically engineered rabbit, Alba, which glowed by expressing a green fluorescent protein (GFP) extracted from a jellyfish. As a transgenic creation, Alba was not permitted to leave the lab.

erupting as a result of the advance of life sciences research and its application.” (Myers, 2015 : 7), bioart is the manipulation and subversion of life, from a molecular or cellular scale to whole organism structure and function, “from bacteria to bunnies, from frogs to flowers, living organisms grown or bred in unique ways, modified or invented by artists, are the elements of a true art of evolution.” (Kac, 2007 : 12)

Whilst bioart involves direct biological manipulation, the genre is highly integrated with related practices from the life sciences, computer sciences, and myriad other art forms (Anker, 2014). It is multimodal, technoscientific and highly collaborative, often requiring specialist technical facilities and expertise. Highly process-orientated and embedded within other research domains, much bioart work takes place within the laboratory and draws on expertise from the natural and physical sciences as well as other knowledge domains. Laboratory tropes are also frequently incorporated into the mode of public display, with scientific apparatuses forming an integral part of the final artwork’s construction and presentation (Da Costa and Philip, 2010 ; Latour and Woolgar, 2013). Examples include *Victimless Leather (Tissue Culture Art Project)* involving cultured bovine cells; *Drosophila Titanus* (Andy Gracie) presenting the fruit fly *Drosophila melanogaster*, *Meta_bolus* by (Saša Spačal and Mirjan Švagelj) featuring *Streptomyces* bacteria, and *Paired Immunity* (Marta de Menezes and Luís Graça) immortalising their own immune cells in vitro. Such apparatuses play an important functional role, providing a life support system for the biological subjects. They also form part of the staging of the organism, an aesthetic framework built into the overall design affecting viewer engagement and interpretation. Curatorial frameworks for the exhibition of such works are discussed in *Curating Lively Objects* (Muller and Seck Langill, 2022), particularly in relation to works made with biological data sets (Cook, 2022), biomedical art (Dean, 2022), and semi-living artefacts (Catts, Salter and Zurr, 2022).

This connection with laboratory driven, technologically advanced areas of scientific research - such as genetic engineering, synthetic biology, epigenetics, and gene-cloning - presents significant social and ethical considerations. Bioart, whilst often utilising the tools and instruments of science, is often simultaneously critiquing the very systems of its creation.

Bioartists create objects, images and experiences which call into question the nature of scientific research, raise pertinent questions about what advances we should be making with biotechnological tools, and invite speculation on future biodigital scenarios.

Unlike conceptualism, which highlighted the use of ideas, language, and the documentation of events, bio art emphasizes the dialogical and relational (e.g., crosspollination, social intercourse, cell interaction, interspecies communication) as much as the material and formal qualities of art. (Kac 2007 : 19).

It is this dialogical and relational aspect which forms a strong connection with ecological art (ecoart), moving out from the laboratory and into the field through transformative practices engaging with interrelated eco-systems. From our earliest renderings of significant life forms on cave walls, through centuries of landscape painting, animal symbolism and allegorical representation, humans have developed visual and sculptural languages which reflect our changing relationship with our habitat and its cohabitants. Within Western contemporary art during recent decades, coinciding with the 'ecological turn' of the 1960s, this relationship with nature has been explored in more than representational ways, through the intervention and manipulation of 'natural' materials, bringing nature into the gallery and taking the gallery into the field. From the monumental land art impositions of Robert Smithson to the temporal interventions of Richard Long, artists have long manipulated environmental conditions. Others have 'employed' living creatures in the construction and display of gallery works, such as Marc Dion's natural history installation, *The Library for the Birds of New York and Other Marvels* (2016), or Céleste Boursier-Mougenot's guitar playing aviary, *From Here to Ear* (2016), both involving live birds in the activation of the artworks. Other examples include the multi-media presentations of leaf-cutter ants in the work of Kuai Shen and the human/dog relationship explored through the work of Maja Smrekar.

The most ecologically sensitive works are those that take a systems approach, examining the social structures intersecting with the ecological considerations (Burnham, 1968 ; Shanken, 2015). Key examples of such complex interrelated works include Agnes Denes' *Wheatfield* (1982), which involved the artist sowing seed on a prominent (and expensive) piece of real estate in Lower Manhattan, New York. The landfill site was transformed into a field of golden wheat, which was then harvested and distributed by the local community - a

large-scale intervention created through numerous interconnected strands of social, bureaucratic, administrative, and imaginative process. The harvested wheat then toured to national galleries, thereby further distributing both the artefacts of the creative act, but also the central ideas raised by the work, the wheat carrying symbolism and signification. Another example of conceptual and material propagation as 'social sculpture' is Joseph Beuys' contribution to Documenta 7 in 1982 (*documenta 7 - Retrospective - documenta*, no date), the community planting of 7,000 oak trees. Twenty-five years later, in 2007, the artist duo Ackroyd and Harvey harvested acorns from the surviving trees in Kassel, Germany, and germinated them (*Beuys' Acorns | Ackroyd and Harvey*, no date). The growing samplings have since toured cultural venues, participated in exhibitions, and stimulated discussion at environmental protest events linked with Extinction Rebellion and Culture Declares Emergency – the living artefacts carrying concepts and questions. Whilst these works utilise living matter and affect environmental conditions in their making, they also possess a strong social (and often political) engagement, activating the work through the creation of public realm encounters, experiences, and performative actions. It is the integration of the social with the biological where a deep ecological integration can occur and where the work under discussion is situated.

2.2.2 Social Systems at Play

The environmental interventions of artists such as Denes and Beuys in the 1980s influenced a larger post-studio movement, taking artist practice into the public realm, encouraging participation and introducing performative elements into the vernacular of everyday existence. This time was also a catalyst for new forms of social and situated practices, with the growth of urban explorations through the Situationist Movement (Plant, 2002), FLUXUS happenings (Kellein and Hendricks, 1995), and psychogeography, which advocated for the aimless exploration of the urban environment through the subjective and relational 'art of wandering' (Coverley, 2006). These *dérives* in the public-sphere developed alongside the growth of community arts from the 1970s onwards and participatory arts in the 1990s (Bishop, 2012 ; Bala, 2018). The art of the everyday was raising recognition as a valid aesthetic and social practice, challenging the reification of the art object, encouraging

people to see the familiar through fresh eyes, and challenging norms of public behaviour. These forms of social participation were at once political, provocative, and playful.

Relational aesthetics (2009), a term created by French art critic Nicolas Bourriaud in the 1990s, is defined as an approach to art-making centred on human interrelations and social contexts, often with a behavioural slant. Shifting the focus from the making of things to the creation of events the theory considers subjective interactions possessing no form, only relational interpretation of other things and beings. For Bourriaud, relational aesthetics “does not represent a theory of art, this would imply the statement of an origin and a destination” (ibid : 19) but a “movement of thought” (ibid : 95) through an ongoing exchange.

In her book, *Artificial Hells: participatory art and the politics of spectatorship*, Claire Bishop (2012) picks up on Bourriaud’s thesis and extends the examination of practice “where people constitute the central artistic medium and material” and the artist operates “less as an individual producer of discrete objects than as a collaborator and producer of situations” (ibid : 2), their role often involving facilitation, initiation, invitation and provocation. The dialogical nature of the situation is notable, demonstrating a shift from ‘art as product’ to ‘art as process’ and audience status from viewer to participant. Naturally there are questions about authorship and agency within such arrangements, around who creates the conditions and sets the agenda, or who participates and with what level of autonomy. Often the artist instigating the relational encounter creates rules, scripts, or prompts in order to distance subjective control and allow open interpretation, to outsource the decision-making process or to create surprising outcomes. The sociological drivers of participatory art attend to consideration of community, equality, engagement, and empowerment, but not exclusively as “participatory art is not only a social activity but also a symbolic one, both embedded in the world *and* at one remove from it” (ibid : 7). Participation permits a means of stepping back and looking at a situation afresh, entertaining novel alternative realities. The alternative realities presented here pertain to the subjecthood of a single-celled organism and the multimodal encounters created through artistic research methods.

Other key influences into how social and participatory aspects feed into the creation of the work are drawn from educational philosophy and pedagogic discourse, in particular

consideration of communities of practice (Wenger, 1998), a philosophy of play (Sicart, 2014 ; Henricks 2015), and complexity theories of learning (Mason, 2008). The working methodologies also reference the citizen science movement (Dickinson and Bonney, 2012), which draws a broad range of non-specialists into a collective research process; tactical media practices (Raley, 2009), which merge art, activism and situated interventions²; and the biohack movement (Meyer, 2020), which operates as a transient collective of biology and technology creatives operating outside of institutional bounds, often with specific community interests and agendas³. In recent decades, as environmental concerns have heightened, there has been a notable growth of public realm art/science research. Examples include the community field work activities (or eco-actions) of artist/ecologist Brandon Ballengée (*Eco-Actions*, no date), studying the impact of industrial pollutants on amphibian populations, and *Hack the Panke*, a multidisciplinary collective bringing public audience/participants into ongoing investigations of the local river system (*DIY Hack the Panke*, no date)⁴.

The work presented in this thesis combines such participatory processes of public realm research, bringing people together to engage in creative and critical enquiry, and creating the conditions for interdisciplinary and interspecies encounters. The practice is nomadic, taking different forms as it travels, each iteration extending methodological and conceptual reach through the combination of practices. The *social* and *relational* considerations within *The Physarum Experiments* form a particular approach to *living systems art*, merging the biological, ecological, and social within a methodological framework. In practice, living systems art adopts methods from multiple research contexts to experiment as praxis with situated encounters and site investigations, creating feedback loops across scales and between species. Through discussion of the work, in its methods and outcomes, I define living systems art as grounded in open exploration, enquiry driven practice, and embodied

² Tactical media refers to ‘artist’ activity which combines art and activism to challenge dominant political and bureaucratic paradigms. Key protagonists include collectives such as Critical Art Ensemble.

³ Notable practitioners include artist and engineer, Natalie Jeremijenko, and Hackteria, a loose international network of biohackers.

⁴ One of several projects curated by Art Laboratory Berlin (ALB) which have activated their local context as complement to their gallery activity. See also my earlier public realm research with ALB, *Swarm | Cell | City*, presented later in the commentary.

in experience, as “the true accent of the art of today is not in the production of things but in the creation of experiences” (Kac 2007 : 24). The work at the centre of this thesis takes a systems approach - a form of social cybernetics (Thompson Klein, 2013 ; Pearl, 2021) - examining the complex interrelationships between organisms, communities, and environments.

2.3 The Curious Organism: Slime Mould in Science and Art

The artistic research presented in this thesis has been created working with one particular living system, the slime mould *Physarum polycephalum*. Here, the organism is introduced biologically and in relation to the significant scientific interest surrounding it. Core to the interdisciplinary nature of the research, diverse areas of enquiry are introduced, to provide contextual explication of its innate biological characteristics - within and between different disciplinary frameworks.

2.3.1 The Many-Headed Amoeba

Physarum polycephalum is an amoeboid organism which defies easy classification. Not plant, animal, nor fungi, it is a unicellular organism which, in its natural habitat, creeps around the forest floor feeding on rotting vegetation. It is one of around 1000 known species of myxomycetes (slime moulds) (Stephenson and Stempen, 2000) which live in temperate woodland environments around the globe. It is a single-celled organism, but multinucleate, comprising a multitude of cells operating as one single entity. This supercell contains thousands, often millions, of individual nuclei shuttling around inside a shared membrane, distributing nutrients and environmental information across a dynamic network of interconnected veins. Its growth behaviour follows bifurcating branching patterns when foraging, a common morphological strategy for many natural phenomena (such as leaf venation, river branching, or blood vessel distribution), and forms tubular connections once food is found, thereby forming a network. Its name, *polycephalum*, translates as ‘many-

headed' due to its nomadic pulsing form, trajectories of growth pushing and pulling in many directions simultaneously.

The slime mould is essentially a brainless blob, without any sensory organs or central nervous system, navigating its environment through a process of chemical sensing known as chemotaxis. It is biologically interesting on several grounds: it has a peculiar life cycle and can, when resources are scarce, choose whether to transform into a stalked fruiting body containing spores to catch on the wind, or to dry up into a dormant state, to be later awoken through rehydration. Based on its dual status as both a eukaryote organism (possessing complex cells containing a nucleus and organelles, such as animals, plants, algae and fungi) and a prokaryote organism (one of the simplest forms of life possessing minimal cell structure, such as bacteria and archaea) at different stages of its life cycle, the slime mould possesses a high variability of reproductive behaviours, reportedly known to have 720 different reproductive sex states (Adler and Holt, 1975). Taxonomically, it has shifted classification over time - once thought to be part of the fungi kingdom due to similarities in growth behaviours and spore development, but now recognised as a protist. It is also of scientific interest because of its motility characteristics (its pulsing cytoplasmic flow) and its seemingly altruistic behaviour (some individual cells sacrifice themselves for the sake of the whole).

Slime moulds are thought to be over a billion years old (Bonner, 2015) but without any significant fossil record due to their soft-body morphology, their true evolutionary development is somewhat uncertain. Over time they have been known to intrigue many, including Japan's Emperor Hirohito (1901-1989), a keen naturalist and mycologist who, in 1929, identified a new species within the grounds of Tokyo's Royal Palace Gardens (Sharp & Grabham, 2015 : 83). Slime moulds have featured in natural history films for almost a century, from Percy Smith's early pioneering techniques of 'time magnification' in the 1931 film *Magic Myxies* (Smith & Field, 1931), to a more recent BBC Nature's series on *The Great British Year* (2013), and in the feature length documentary, *The Creeping Garden*, dedicated to plasmodial slime moulds and the curious humans who work with them (Grabham & Sharp, 2014), which extensively features my work with slime moulds and other living systems.

The cultural and biological interest in slime moulds is long standing, but it is particularly in the early part of the 21st century that interest has grown, slime mould serving as a model organism in the fields of biophysics, computational biology, robotics, and behavioural science. This contemporary interest in the slime mould is based largely on its capacity to solve problems, optimise networks, and demonstrate learned behaviour, but also, I argue, as an epistemic (and ontologic) tool for posthumanities discourse.

2.3.2 Scientific Enquiry and Biological Computation

Outside of their natural habitat slime moulds have increasingly been used as a model organism within laboratory research, with experiments seeking to better understand its biophysical properties, the dynamics of information distribution within the supercell and significant capacities for problem-solving without a brain. A seminal moment in slime mould research was the published account of a scientific experiment which tasked the slime mould with solving a maze (Nakagaki, 2001). Having navigated the paths through the maze, connecting between two food sources, the slime mould repeatedly rationalized its growth to establish a single connection through the shortest and most efficient route. The account of the experiment, led by Professor Toshiyuki Nakagaki, concluded that ‘this remarkable process of cellular computation implies that cellular materials can show a primitive intelligence’ (Nakagaki, 2000: 470). This comment sparked heated debate among the scientific community about how ‘intelligence’ is attributed to living matter and how it can be defined in non-neuronal organisms. Semantic arguments followed, disputing definitions of ‘smart’ versus ‘intelligent’, or ‘conscious’ versus ‘sentient’, much of which revealed cultural and linguistic biases rather than firming up any scientific grounding (Narby, 205 : 104)⁵. However, the debates raised wider questions around perceptions of intelligence in nature which have extended in recent years to include similar discussions relating to other living systems, such as the intelligence of the forest – colloquially known as the ‘wood-wide-web’ - through the coordinated behaviour of mycelial fungal networks (Wohlleben, 2017; Kohn, 2013; Tudge, 2006) or within the complex systems of plants (Calvo, 2022; Ryan, *et al.*, 2022).

⁵ The semantic distinctions surrounding definitions of intelligence centred largely on differing cultural and philosophical traditions between Japanese animism and Western mechanistic rationality.

These attributions of intelligence to nonhuman forms of life are not entirely new, for some date back to the turn of the last century (Gentry, 1900). However, new techniques and methods, and a shift in environmental mindset, have opened up questions which decentre the human from species hierarchies.

While there is still much unknown (or undecided) about how the slime mould performs ‘intelligently’, it is widely held within the scientific community that the source of the slime moulds impressive capabilities is the pulsing oscillations within its vein-like network, the rhythmic and dynamic force of protoplasmic streaming (Fig 08). Despite such a simple cellular structure (a bunch of cells sharing a cell membrane inside a protoplasmic gloop) the slime mould is also attributed with other achievements, including an externalised spatial memory (Fig 9) (Reid *et al.*, 2012), temporal memory and the capacity to anticipate events (Saigusa *et al.*, 2008), and the ability to learn from its environment and share that learning with other slime moulds, even after lying dormant for over a year (Vogel and Dussutour, 2016).

The mathematical questions posed by these inherent biological behaviours have been explored in other experimental research, such as the replication of the Tokyo transport system (Tero, *et al.*, 2010), numerous classical problems of computer science, such as the one-armed bandit (Reid *et al.*, 2016), the traveling salesman problem (Zhu *et al.*, 2013) or a speculative rerouting of the UK motorway system (Adamatzky and Jones, 2011). In recent years slime mould has mapped the world, including historical colonization and trade routes such as the Silk Road and Asian Highway (Adamatzky, 2012) and even extending to space exploration, speculatively concluding that “the protoplasmic network is a good biological model of a colonization network which could emerge in future Moon missions” (Adamtasky *et al.*, 2014 : 14).

2.3.3 Slime Mould in Art, Design and Architecture

Other areas of research are also working with the organism to understand systems of information distribution and network formation. The questions the organism raises about the fundamentals of self-organisation, network optimization, and non-hierarchical

structures are of interest to the schools of design, urban planning, and architecture. For the slime mould, being able to optimize networks allows for efficient sharing of nutrients across the entire body of the supercell. It also permits information to be distributed efficiently across the whole morphological system which, biologically, creates advantages over less dynamic body plans. Humans seek to understand how the organism is doing this in order to apply the same logic to more anthropocentric systems such as infrastructure design and resource distribution. Studies using slime mould algorithms (SMA) have been used to assess existing physical networks and to test theoretical networks for potential future application, for example in analysis of the demand estimations of urban water resources (Yu, Liu and Chen, 2021) or the efficiency of the energy distribution of solar photovoltaic cells (Kumar *et al.*, 2020).

As a speculative tool, slime mould has been employed by design studios such as ecoLogicStudio⁶ who have, since 2013, worked with '*polycephalism*' as a material substance and conceptual framework for rethinking urban planning considerations for the twenty-first century. Working with slime mould as both a wet design tool and as a computational model, their work proposes a concept of 'bio-citizenship' based on an "interdependence of digital and biological intelligence in design by working directly with non-human living organisms" (Pasquero and Poletto, 2019 : 60). Other biologically inspired urban design studies employing slime mould acknowledge the organic 'messiness' of city infrastructure (Dillon *et al.*, 2019) and the need for interspecies thinking to address the conflicting interests, needs, and support systems of the many agents co-existing within an urban plan (Gruber *et al.*, 2019).

Through the period of my own research working with slime mould, a growing number of artists have also worked with the organism, materially, conceptually, and computationally⁷. For example, social and political systems are critically examined in Michael Sebdon's bio-

⁶ My collaboration with ecologicstudio is presented in the portfolio (Fig 10).

⁷ It is important to note that all the projects cited here occurred after or simultaneous to my own work with the organism. Some cite direct influence and inspiration for my work, others have emerged adjacently. Many of the artists cited I have interacted with in cooperation or collaboration over the years.

hybrid machines in *Ctrl*, a Biotic Game⁸ where 10 plasmodia compete in a Game of Life⁹. The biodigital artwork harnesses the electrical charge of slime mould as ‘gaming data’ within an interface to “translate ‘aesthetically’ a sense of ‘organic motions’” (Sebdon, 2019 : 312). Interdisciplinary artist Nenad Popov worked with slime mould to create a meditative audio-visual installation, *Pulse, Flow*, (2013) visually tracking the organisms growth in real time and translating the rhythmic pulse to a visual projection, “offering an immersive experience of the internal liquid fluctuations within the slime mould” (Popov, 2019 : 228). New media artist duo Cesar and Luis developed a biodigital artwork, *Degenerative Cultures* (2018), where slime mould redacted a twitter feed (Solomon and Baio, 2021) and in 2014 bioacoustician and composer Eduardo Miranda staged a human/slime mould duet creating a frequency feedback loop between a grand piano and a slime mould culture (Miranda, Adamatzky and Jones, 2011).

German artist Teresa Schubert has worked with slime moulds alongside other networked microorganisms such as fungi and bacteria. *Somniferous Observatory* (2011-2013) is a series of photographs observing the growth patterns of the organism under the influence of psychoactive and somniferous substances (Schubert, no date). Later, developed in collaboration with unconventional computer scientist Professor Andrew Adamatzky, Schubert created *Bodymetries* (2013-15), an interactive body-mapping projection, where a computer simulation of *Physarum polycephalum* navigates the terrain of the human body, seeking the shortest route between moles on the artist’s skin (Schubert *et al.*, 2016). Other performative strategies have been employed by Jenna Sutela in *Many-headed Reading* (2016), a performance involving the ingestion of slime mould and a recital of texts exploring the interconnections between organisation / organism / orgasm (Sutela, 2017).

The social and decision-making properties of slime mould have also been harnessed in creative pedagogies. For example, bioartist Blaine O’Neill employed the slime mould as a community mapping tool to help the residents of North Troy, in upstate New York, discuss

⁸ Biotic Games is a field of research developed by Ingmar Riedel-Kruse and lab at Stanford University which incorporate microorganisms as agents within arcade-like gameplay.

⁹ James Conway’s 1970 Game of Life was a seminal moment in cellular automata and computational thinking and is oft cited in contemporary game theory.

improvements to their environment ('Community Mapping with Slime Mold' w/ Blaine O'Neill, 2013). Artists Sarah Choukah, WhiteFeather Hunter and Tristan Matheson worked together to develop a series of public facing workshops to explore the 'plasmodalities' of *Physarum* (Choukah, Hunter and Matheson, 2019) working with the organism as a form of 'social media', and artist and teacher Oliver Kellhammer has used slime mould as an oracle to help in mundane daily decision-making. In his teaching at Parson's School of Design, Kellhammer has also engaged slime mould within a student brief to redesign a New York City park from the perspective of nonhuman inhabitants (Kellhammer, 2017). Another educational establishment, Hampshire College, 'employed' *Physarum polycephalum* as a Scholar in Residence (Hampshire College Welcomes First Non-Human Scholars-In-Residence, 2017 ; Dobro, Halliday and Keats, 2019). *The Plasmodium Consortium*¹⁰ combined art, philosophy and biology to engage students and slime mould in the modelling of human problems. Poverty, drug trafficking and border control issues were tested in a petri dish, with the results analysed and the findings sent to government officials as recommendations for policy decisions. Other philosophical exploration on the subjective sensibilities of the organism include dedicated chapters on slime mould in Steve Shaviro's exploration of consciousness, *Discognition* (2016), and Evelyn Fox Keller's examination of the epistemic value of slime mould in Sherry Turkle's (ed) *Evocative Objects: things we think with* (2011).

The practitioners cited are, in different ways, working with the living media potentialities and the transferable concepts of the organism as a means of speculative thinking. By thinking *with* slime mould, issues can be viewed from diverse perspectives and played with directly and indirectly. Many of these approaches echo my own intentions, objectives and methods working *with* and *through* the organism, a simultaneity of emerging practices which are indicative of a larger 'living systems turn'.

¹⁰ The Plasmodium Consortium was a hybrid art, biology and philosophy project initiated by contemporary philosopher Jonathon Keats and enacted by curator Amy Halliday and biology professor Megan Dobro.

2.4 Theoretical Frameworks: Thinking *with* / Thinking *through*

The research presented is informed by critical theory and, in turn, the thinking is informed by creative modes of enquiry - practice and theory in constant dialogue. The theoretical backbone of the work embraces thinking from the history and philosophy of science, from eco-philosophy and posthumanities discourse, and from science technology studies. Much of the work involves thinking through doing and, as such, many of the works adopt an approach akin to practical philosophy, through thought experiments and embodied enactments of concepts.

Influential writings from the fields of new materialism, science technology studies (STS) and eco-philosophy include Jane Bennett's work on the vitality and agency of matter (2010); Timothy Morton's treatise on being ecological, attuning to other species and embracing a certain level of anthropomorphism (2018); and Donna Haraway's work on symplectis and response-ability (2016). Historical perspectives on our current ecological turn are provided by Jakob von Uexküll's consideration of species subjectivities (1992), and Fritjof Capra's treatise on the web of life, systems thinking and cybernetics (1997). The participatory practices have been informed by pedagogic philosophies and considerations, most notably theories on communities of practice (Wenger, 1998), democracy of learning (Freire, 1993), and complexity theory within a philosophy of education (Mason, 2008). Play and playfulness are also important features of the participatory framework, creating both a mode of exploration and a conducive atmosphere within which that exploration can take place (Sicart, 2014).

Subject readings on distributed networks, collective behaviour and principles of emergence have informed subject knowledge and influenced methods, intentions, and outputs, including Peter Miller's book on swarm intelligence (2010); Philip Ball's writing on critical mass (2005); Steven Johnson's seminal book on emergence across species and systems (2002); and Christopher Vitale's philosophy of networks (2014). Many other readings have influenced the making of the work, which will materialise in the discussion relating to the

nature of material thinking (Bolt, 2007), art and experience (Dewey, 2005), communities of practice (Wenger, 1998) and a process philosophy of biology (Nicholson and Dupré, 2018).

Theories which are prescient within the critical contextualisation of the work include definitions of *experimental systems*, within the domain of science (Rheinberger, 1997) and within artistic research (Schwab, 2013). Historian of science, Hans-Jörg Rheinberger (1997) defines experimental systems as the conditions and contexts for experimental enquiry, containing apparatuses and technical objects. It is through experimental systems “that the objects of investigation become entrenched and articulate themselves in a wider field of epistemic practices and material cultures, including instruments, inscription devices, model organisms, and the floating theorems or boundary concepts attached to them.” (Rheinberger, 1997 : 29). Within my experimental system, organisms, imaging technologies, and pedagogic practices are assembled, reassembled, and manipulated.

Through these systems of enquiry, the slime mould becomes a *boundary object* (Star and Griesemer, 1989 ; Star, 2010)¹¹, a dynamic object which is open to diverse interpretation by individual members of a community, yet consistent enough in form to mediate between parties. Originally used in a sociological context, the concept of boundary objects has been applied to educational communities (Wenger, 1998) and cross-disciplinary collaboration (Nicolini, Mengis and Swan, 2012). Here, the slime mould is examined as a boundary object intended to elicit imaginative speculations and ecological interconnectivity, a translation device at an interdisciplinary crossroad where boundary work forms “part of the entanglement between the two cultures argument and public engagement in science [and provides] a way to begin to untangle the complex relationship between interdisciplinary work in art and science” (Halpern, 2012 : 925). Boundary work is also addressed in relation to the “fuzzy epistemology of artistic research” which invites “unfinished thinking” (Borgdorff, 2012 : 181). Within and between disciplinary contexts, the organism carries flexible signification, interpretation, and symbolic meaning, engendering the emergence of new definitions and discourse.

¹¹ The term *boundary object* was introduced in the late 1990s by feminist science and technologies scholar, Susan Leigh Star, defined as “a sort of arrangement that allow different groups to work together without consensus.” (2010 : 602).

Theories of *nomadic concepts* relate to how meaning is constructed, and reconstructed, in the process of translation between knowledge domains and contexts. The idea of nomadic concepts was first developed by Isabelle Stengers (1987) and has been taken up and extended by other scholars, such as the traveling concepts of Mieke Bal (2009) and interdisciplinary concepts of Ernst Müller (2011). It is a means to think *with* and think *through* behaviour, phenomena, and material matterings (Barad, 2014) of the world. Operating within interdisciplinary and intercultural settings, these theories cast the slime mould as a material-semiotic object (Bolt, 2007), a concept carrying living subject.

3. The Published Works



The Physarum Experiments: Growth Studies #3 Elaboration

3.1 Introducing *The Physarum Experiments*

In this encounter the human is no longer outside of the assemblage directing the proceedings. The human being becomes just one material-semiotic actor engaged in complex conversation with other players.

(Bolt, 2007 : 2)

This written commentary contextualises a portfolio of published works comprising artworks, artefacts of experiments, and documentation of co-enquiry events, alongside published peer-reviewed and editorial writing. In addition to ‘making things’ such as films, objects, and texts, there is also a significant component of ‘making things happen’ through participatory, performative, and action-based works. Highly exploratory and open-ended, the work has developed intuitively and iteratively, evolving through numerous encounters, insights, and experiences.

In describing, analysing, and contextualizing the published works, this section is structured thematically rather than strictly chronologically, though a timeline of influence and evolution should be apparent. Material investigations are first discussed (3.2), introducing my own encounter with slime mould and working with it as a living material possessing inherent characteristics and agency. Systems of co-enquiry are then introduced (3.3), describing the methods and practices which I have developed to bring other curious humans into contact with slime mould and its related concepts, through workshops, talks, and collective experiments. The two strands of research have co-evolved in dialogue, intertwining slime mould and human ontologies and epistemologies.

Processes and outcomes have been articulated through authored and co-authored texts published in different contexts (Barnett et al., 2016 ; Barnett, 2019a ; 2019b ; 2022 ; 2023), which are included in the portfolio of published works (Portfolio B3: Published Texts).

3.2 Material investigations: working with single-celled intelligence

My investigation *of* and *with* slime mould started in 2009, following a lab visit to the microbiologist Dr Simon Park¹². Unbeknownst to me at the time, his departing gift was to spark over a decade of interdisciplinary enquiry that has produced dozens of films and time-lapse studies, developed novel methods for working artistically with living systems, connected with multiple trajectories of multidisciplinary research, and engaged thousands of people in co-enquiry through workshops, talks and collective experiments.

The invitation to visit Dr Park's laboratory at the University of Surrey was prompted by my previous work with biological matter, in particular working with microorganisms ('Cultured Colonies', 2000) and microscopic cellular structures ('Cellular Wallpaper', 2000)¹³. On leaving, I was presented with a petri dish containing a small blob of yellow slime mould and given just a few simple care instructions: the organism needed to be kept in a dark and damp environment and it had a dietary preference for porridge oats. So began an exploratory empirical enquiry, a process of getting to know my new living material.

Initial investigations were focused on understanding the organism through growth and observation. A range of habitats were improvised in the studio and different culinary offerings made (Fig 13). My early experiments focused on the slime mould's aesthetic material properties to generate unpredictable expressive structures; the emergent spatial patterns produced by the organism were engaging and beautiful. As I observed slime mould growth, I developed techniques for photographing the ensuing behaviour using a time-lapse photography rig to capture the dynamic forms (Fig 11), which were then developed into film studies and animations. Through experimentation I learnt that the characteristics of growth patterns were affected by several variable conditions, including the choice of moist substrate (felt shapes, cast agar, tissue paper), food source (pasta, rice, flour, vegetation

¹² Dr Simon Park was a curious, creative and hugely generous microbiologist, who collaborated with numerous artists and supported many interdisciplinary activities (Bright, 2022)

¹³ Prior to working with slime mould, my artistic research had involved working with different living systems, including microorganisms, botanical specimens and model organisms in a range of contexts from botanical gardens, hospital pathology labs and life sciences research centres (see www.heatherbarnett.co.uk for details).

from the garden, mushrooms) and environmental conditions (temperature, light, humidity). The process of trial and error - observing reactions and adapting my interventions - allowed me to learn directly from the organism, building a deep tacit knowledge of its inherent biological characteristics. This life study was complemented by desk research exploring academic slime mould studies, reviewing biological papers as well as many other areas of slime mould inspired enquiry (see section 2.3). This combination of explicit research (reading published literature) and improvised observational study (working with the organism in the studio) developed a multimodal methodology (Malina, Strohecker and Lafayette, 2020) allowing for critical and creative trajectories to intersect and co-evolve. What I was observing in the organism was corroborated in the literature, what I was reading in the literature was manifested in my empirical observations. Early on in this process it also became clear that, beyond the pure aesthetics inherent in slime mould growth, there lay the potential to explore the metaphoric power of slime mould in a far deeper sense. As a social organism possessing intriguing analogous characteristics, the slime mould offered numerous challenges to our understanding of intelligence and intention. Additionally, this model organism presented fundamental ontological questions about communication, cooperation, and environmental adaptability.

3.2.1 Experimental Systems

Methodologically, the research produces a model of artmaking where the work is co-created by two organisms (human and nonhuman) through a process of invitation and interruption, mediated through interconnected technological and biological media and with the outcomes emerging through a performative stimulus and response. The 'stage' becomes a platform for interspecies interplay, each study prompted by speculative questions relating to behavioural predictions, based on navigational, genetic, or environmental encounter.

The space within which this exploratory questioning takes place is hybrid in form and function, bringing together the apparatuses from the laboratory and the studio, combining clean room protocols with intuitive material investigations (working with both living and inanimate matter) (Figs 11-14). Technological modes of mediation translate the biological

behaviour through the choice of camera lenses, lighting, staging and time-lapse interval rates. This hybrid space operates as an *experimental system*, a practice-driven ‘packaging’ of concepts, cultures, and actions within a framework of enquiry (Rheinberger, 1997). Within this system an interplay of phenomena, processes, and apparatuses result in the creation of time-lapse studies, merging explicit and tacit knowledge *in and of* the organism (Figs 02-07, 10). For example, in my homage to the classic scientific study which demonstrated primitive intelligence, *Study No.019: The Maze* (Fig 04), the slime mould separates and fuses as it explores a three dimensional maze shifting its collective mass to suit environmental need; in *Study No.026: Intraspecies Fusion* (Fig 07), an encounter between genetically identical slime moulds observes a moment of hesitation followed by a synchronous fusion event involving the sharing of chemical information; or in *Study No.024: Interspecies Encounter* (Fig 06), strategic defense strategies are revealed when two differing species meet.

These growth experiments form a methodological *assemblage* combining biological characteristics of the organism, scientific readings, and creative studio practice. Explicit knowledge directs the frame of exploration, whilst embodied knowledge directs the ‘nudging’ of improvisation during growth, as the slime mould responds to given stimuli. The result is a system of structures and parameters that navigate between prediction and surprise. *Assemblage*, in this context, is a conglomerate of encounters, memories, environmental factors and interconnected life forces (Bennett, 2010 : 23), within which the slime mould becomes an *actant*, what Bennett defines as “a source of action that can be either human or nonhuman ... which has efficacy, can do things, has sufficient coherence to make a difference, produce effects, alter the course of events.” (ibid : viii)¹⁴. Within my research the nonhuman actant operates as an experimental system in and of itself, the organism embodying material, conceptual, and phenomenological knowledge, within which novel outcomes can emerge. Here, the slime mould becomes a co-creator in the making of artworks, a *material-semiotic actor* (Bolt, 2007 : 2), the organism’s inherent characteristics providing aesthetic and philosophical curiosity to emerge through technological intervention, carrying embodied onto-epistemological signification. Time-lapse photography becomes a mediation device enabling a shift between spatiotemporal subjectivities of

¹⁴ ‘Actant’ is a term coined by Bruno Latour and taken up by Jane Bennett in her discussion of the liveliness of matter (2010)

human and slime mould (Barnett, 2023). The intervention of the imaging technology permits a portal between two sensory worlds.

3.2.2 Amplification of species subjectivities

The conceptual, technical, and aesthetic considerations of the time-lapse studies have been discussed in several peer-reviewed published works included in the portfolio (Barnett, 2019a, 2019b, 2022), (See Portfolio: Published Texts 2, 3, 4). Most notably, the works have been discussed within an interdisciplinary publication *Drawing Processes of Life: molecules, cells, organisms* (Anderson-Tempini and Dupré, 2023)¹⁵. The chapter I contributed, 'Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life' (See Portfolio: Published Text 5), provides an account of the experimental systems developed, through interspecies studio practices, in creating the time-lapse films elucidating on the embodied intelligence of the organism.

The chapter makes connection between the scientific literature demonstrating particular traits, such as learning, memory, navigation, and how this learning has come to play within the creation of the time-lapse studies, a dialogue between the explicit knowledge held within in the scientific literature and the embodied knowledge held within the pulsating organism - and as mediated through the lens of the camera and the computational composition of the films. The central thesis of the chapter elucidates a process of *drawing out* behavioural characteristics held within the body of the organism and *drawing in* the viewer in a reciprocal exchange.

The spatiotemporal worlds are explored through the intersubjectivities of time related to the sensory perception of different organisms and the *ömwelt* within which they exist. The

¹⁵ Following an invitation to present my research at a seminar hosted by Egenis, the Centre for the Study of Life Sciences at the University of Exeter, in November 2019, I was invited to contribute a book chapter to a publication examining drawing as an epistemological tool for understanding the complex processes of life. The book forms the culmination of an interdisciplinary AHRC funded research project led by artist researcher, Gemma Anderson-Tempini, working in collaboration with professor of philosophy (and director of Egenis), John Dupré, and biologist James Wakefield.

term *ömwelt* (literally meaning ‘surrounding world’) was first coined by naturalist, Jacob von Uexküll, in his 1934 essay, *A Stroll through the Worlds of Animals and Men: A Picture Book of Invisible Worlds*, in which he acknowledges the highly individualized sensory subjectivities of all creatures. His thesis moves away from the mechanistic interpretations of life prevalent at the time and posits animals and organisms as ‘subjects’, not ‘machines’, operating through a complex interrelation of perceptions and actions (Uexküll 1934: 320). The subjective experience of any given organism, he asserts, is based on its morphology and metabolism, its relationship with time, and its spatial navigation through a specialized sensorial system enabling it to understand its world.

These spatiotemporal conditions form the basis of the relational aspects of *The Physarum Experiments* time-lapse *Studies*, discussed in the chapter through both historical and contemporary readings of the *ömwelt*. Hans-Jörg Rheinberger’s definition of an *epistemic thing* (1997) – a research object which embodies concepts – is brought to bear in the body of the slime mould. Definitions of (non-neuronal) cognition, intelligence and sentience are discussed through Steve Shaviro’s speculative philosophy on ‘thinking like a slime mould’, allowing us “to observe the mechanisms of thought in something like their primordial form” (2016: 212). The chapter addresses questions of process biology (Nicholson and Dupré, 2018) within the time-lapse studies: how time and space are represented visually, and how imaging technologies are used to mediate relatable *ömwelts*.

The filmic conventions employed in this representational mediation are explored, from the early pioneers of natural history film-making such as Percy Smith, who was the first to capture the complex behaviours of slime mould in action in *Magic Myxies* (Smith and Field 1931)¹⁶, the conventions of modern day natural history cinematography seen in BBC Nature documentaries (such as ‘The Great British Year’, 2013), and the nascent discipline of ecocinema which critically examines the interplay of filmic conventions, human psychology, and environmental concerns (Rust, Monani and Cubitt, 2013). The representational

¹⁶ Percy Smith was an early twentieth-century cinematographer who pioneered time-lapse and microphotography. His inventive films presented the behaviours of organisms as never seen before. See: *Secrets of Nature* (1922–34), which depicted vernacular views of plants, animals, birds and insects.

ambiguities engendered in my own (*non*) *natural history* studies are directly referenced, citing the construction of artificial environments taking the organism out of its ‘natural habitat’, the apparatus of the table-top experiment within a studio setting, the lack of visual referents denoting scale, and the denial of knowledge of ‘real time’ translation. Together, the technical, conceptual, and visual considerations form reciprocal interactions, creating a space for *relational agency* between species. Counter to object-based ontological thinking (Harman, 2018), *relational agency* is a process-based ontology, recognizing the fundamental energy and processual forces driving emergent and adaptive phenomena (Heylighen, 2022). This theoretical frame addresses evolutionary questions limited by definitions of ontological drives such as goal-directedness, purposivity, and mind.

The studio/laboratory environment provided a space to take the organism outside of its natural habitat and into other realms of existence but outside of the studio environment, the slime mould crept. As I published my studies online (Barnett, no date b, c) and presented the films in exhibition (Figs 18-22) I connected with other people working with the organism and its embodied concepts. My work with slime mould became a nomadic practice, echoing the growth behaviours of the subject of study – a meta-method emerging through foraging, locating, and connecting with other curious humans working with this curious organism.

3.3 Systems of Co-enquiry: from single-celled to multi-celled intelligences

The research is nomadic not only in terms of connecting and collaborating with other researchers and practitioners, but in extending connection and collaboration within public domains. Since the early days of working with slime mould I have brought others into the processes of enquiry, by establishing an online network, slimoco: The Slime Mould Collective (Fig 60); through devising and delivering slime mould workshops with diverse groups (Figs 24-29); and developing a series of biosocial collective experiments exploring network behaviour across systems and scales (Figs 30-49). In this section I critically reflect

on these participatory practices, emphasizing the underlying pedagogic philosophies, the modes of multi/inter/trans/a-disciplinary working, and the frameworks for co-enquiry.

In the studio, I created the conditions for the complexity of slime mould behaviour to reveal itself via the construction of conducive environments and the mediation of imaging technologies. In the public realm, I have sought to create similarly emergent conditions for insights and associations to grow, as mediated by the slime mould. Both practices operate within a scaffold of low hierarchies. The methods specifically embrace the underlying principles of emergence to facilitate unpredictable outcomes through open-ended experimentation – the artist as instigator, facilitator, and holder of space - creating the conditions for discovery and insight. Fundamentally, the research is “discovery-led” rather than conventionally “hypothesis-led” (Borgdorff, 2012 : 80) allowing for unexpected events and outcomes to emerge from the environmental conditions established. Employed in both *making things* and *making things happen* is a system of multiple interactions, which create feedback loops and the arising recognition of patterns, which in turn construct meaning¹⁷. Decision-making is distributed within these interactions and outcomes are unpredictable and individuated. I create the framework for those interactions but do not (and cannot) control the outcomes. After all, “emergent behaviours, like games, are all about living within boundaries defined by rules, but also using that space to create something greater than the sum of its parts”. (Johnson, 2002 : 181). An emergent system - whether an ant colony or a slime mould cell, a human grouping or a city - shares these fundamental characteristics and behaviours.

The overarching aims of these emergent processes of co-enquiry are to exemplify the collective and cooperative mechanisms of the organism in practice, providing space for multiple associations, interactions and interpretations. By collectively producing knowledge, an inherently sympoetic practice (Dempster, 2000 ; Haraway, 2016), I aim to break down hierarchies established by disciplinary boundaries and academic structures as well as other demographic factors such as age, culture, and education. I am interested in how differently

¹⁷ These are the fundamental characteristics of any emergent system, where complexity arises from relatively simple elements through dynamic interactions and information distribution, leading to pattern recognition.

the organism is defined, what questions are brought to bear upon it and, ultimately, how people relate to it as a fellow intelligent form of life. Methods employed in these systems of co-enquiry include material thinking, embodied actions, and multiple modes of storytelling, combined as a form of practical philosophy – to think *with* the organism.

3.3.1 Frameworks for the creation of Interspecies Encounters

The pedagogic philosophies and participatory methods developed to bring others into the fold of emergent complexity and living systems enquiry are threefold, working with the slime mould as a living subject of ontological curiosity, an epistemic object of enquiry, and a comparative model for examining relational phenomena (living and nonliving). The practice-based models for public realm research are inherently interdisciplinary, merging methods (and mindsets) from art, science, and philosophy within one experimental system. This framework for bringing diverse ‘experts’ and ‘citizens’ together has built on previous collaborative methods developed through my own transdisciplinary collaborations working with scientists and other disciplinary professionals (Barnett and Whittle, 2006). The methodologies are also influenced by my pedagogic practice in the field of art and science and the related educational models developed, from public engagement workshops in galleries or community settings, to cross-curriculum and interdisciplinary courses established in formal educational settings (Barnett (ed), 2012 ; Barnett, 2013 ; Barnett, Holme and Cohen, 2021 ; Nohara, Marenko and Salani, 2023).

The aim of the co-enquiry is not solely about connecting humans and slime moulds, but also connecting humans with fellow humans who share a common curiosity. The interdisciplinary aspect is important in opening up exchanges, interpretations, observations, and questions, irrespective of specialist domains. The ‘human petri dish’ of enquiry creates the conditions for experimentation and speculation, where interactions and feedback loops drive the generation of individual and collective knowledge. This open system of enquiry can be defined as a “rhizomatic network of recurrent epistemic practices, a filigree of *investigative operations*” (Rheinberger, 1997 : 16), a dynamically operating network of observation, thought, and action which traverses domains, sites, and contexts, engaging distinctly with different groups of people along the way. The *investigative operations* involve a

constellation of methods bringing others into a process of co-operative inquiry (Heron)¹⁸, defined as a condition for experiential and participative investigation through “reciprocal relations with other self-directing persons” (1996 : 11). As a social science framework, co-operative inquiry is defined as a form of democratic action research where all participants are active contributors, not only to the processes of enquiry and the generation of knowledge arising from it, but also to the decision-making involved in defining the very framework for that enquiry. Heron notes the interdependence between thought and action in making “the full range of human sensibilities available as an instrument of inquiry” (ibid : 47) operating through four domains of knowing which interact in a processual interplay between divergent and convergent thinking. Here, in an open system of enquiry, knowledge is generated in multiple ways: experiential (through direct encounter), presentational (the imaginal ability to express patterns), propositional (conceptualizing or theorizing the domain or subject of inquiry), and practical (having relevant skills which can be applied to the inquiry and have the potential for transformation).

These theories are grounded in practice within the social participatory systems and transient communities of practice created as part of *The Physarum Experiments*, through workshops, public engagement activities and, particularly, through a series of bio/social collective experiments developed between 2015 and 2019. Here, the slime mould became a focal point for exploring network operations and emergent systems within and across the urban landscape, which over time generated a dynamic and evolving model for interdisciplinary co-enquiry working with both specialist professionals and general publics.

As “experimental systems are necessarily localized and situated generators of knowledge.” (Rheinberger, 1997 : 76) the methods of co-enquiry travelled to different cities, adapting to each location. Beginning in the streets of New York City, *The Physarum Experiments* migrated to Berlin, Munich, Amsterdam, and Toronto, establishing nodes within a nomadic network of practice-led collective experimentation. Moving between cities allowed for the robust and accumulative evolution of methods through replication, iteration, and

¹⁸ Heron uses the spelling ‘inquiry’ which indicates more formal modes of investigation, whereas I use the spelling ‘enquiry’ to indicate more exploratory, and less formal, modes of asking questions.

adaptation. Reproduction in the system allowed strengths to be reinforced whilst also opening up new insights through differentiated attunements to individual contexts, the multi-faceted elements in an *assemblage*, and the intermingling of diverse disciplinary collaborators with participants bringing their own positions and interests into the enquiry. As Rheinberger asserts, “reproducing an experimental system means keeping alive the conditions – objects of enquiry, instrumentation, crafts and skills – through which it remains *productive*.” (1997 : 75).

In different ways, the cities became productive playgrounds for multi-modal exploration, co-constructing definitions of networks and constantly shifting perspectives between species subjectivities (human and slime mould), and between network behaviour (living and nonliving phenomena). The artmaking within this model of co-enquiry is a form of *relational speculation*, playing with conceptual propositions through a combination of practical experimentation, discursive exchange, and experiential modelling, constantly shifting positions and perspectives between species and scales. It is processual in its creation and transient in its making. It is collectively negotiated, contested, and (re)produced.

3.3.2 City as Superorganism: Biosocial Collective Experiments

The experimental design for collective experimentation is routed in pedagogic philosophy and social practice, creating transient communities of enquiry whose constituent properties form to explore biosocial phenomena for a particular duration, be it a few hours or several days. Representing diverse disciplinary fields, participants and co-enquirers are bound together through a common interest, for example in network mechanisms or multispecies enquiry. Each event connects fundamental knowledge and abstract concept, grounded within local contexts and scenarios, exploring ideas through a combination of material, relational, and behavioural forms of modelling. Ontological and epistemological patterns derived from the slime mould are played out in the city.

To explain how these experimental systems have operated in practice I draw on key examples of biosocial experiments conducted between 2015 and 2019, each an invited

intervention into the city to explore networks, systems, and behaviours across biological, social, and technological strata.

Nodes and Networks (New York City, 2015)

A city-wide experiment bringing together a scientific conference community with a group of local creative practitioners and inviting a group of public participants to engage with experimentation in the laboratory (School of Visual Arts BioArt lab), the gallery (Museum of Modern Art), and the field (Central Park). (Figs 30-35)

Swarm | Cell | City (Berlin, 2017)

As part of the *Nonhuman Agents* exhibition at Art Laboratory Berlin, I collaborated with local performance art duo, plan b, to devise a series of bio/urban mapping experiments to engage a mixed interdisciplinary group of local participants. (Figs 36-40)

City as Superorganism (Amsterdam, Munich, Toronto, 2018/19)

Further invitations came to extend the methods of co-enquiry to other cities in association with the Open Set City Rhythms Summer School (Amsterdam), an urban/nature season of cultural events (Munich) and a university course exploring the city as a complex interconnected system (Toronto). (Figs 41-49)

Integrated within these urban experimental explorations, and operating independently in association with other events and exhibitions, has been an ongoing participatory experiment exploring embodied cognition and nonverbal communication. Since 2013 *Being Slime Mould* has invited groups of people to test their capacity for cooperation against that of a single-celled intelligence. The duration of the activity ranges from a few minutes, working with a conference delegation, for example, to several days working with a group of dancers on a piece of movement research, *Spatial Negotiations* (Malmö, 2017). (Figs 50-58)

Rather than present the processes of co-enquiry as a chronological development I instead elucidate key characteristics, intentions, and methods which have iterated differently through each encounter, cumulatively building the subjecthood of slime mould through interspecies encounters. Common characteristics to the diverse settings include the

interdisciplinary configurations of investigation, the exploratory and experiential nature of experimentation, and the creation of conditions for potential emergence.

3.3.3 Modelling processes at play within Experiment Systems of Co-enquiry

The characteristics held within the system of co-enquiry orchestrate different epistemologies including explicit, tacit, and embodied forms of knowing. Here, I categorise how the slime mould is used within these systems as a model for empirical enquiry and speculative thinking under three dominant headings: material, relational, and behavioural, though it should be noted that these forms of modelling operate in concert, forming cumulative feedback loops of interaction, resulting in an expanded subjecthood of the protagonist organism. Whilst each experiment operated according to its situated context, core elements within the experimental system are consistent – material thinking, metaphorical modelling, embodied actions – though framed differently in each location.

3.3.3.1 Material

Core to each experiment is the direct encounter with the materiality of the organism, an opportunity to confront its liveliness and to *think through doing* in creative and critical experimentation. Material investigations include designing an experimental arena within a petri dish to test particular traits, aid decision-making, or to observe growth trajectories. Questions set can be hypothesis-driven, testing particular theories or predictions but, more commonly, take an exploratory approach, asking ‘what if...’ and observing the results. Materials are provided which create a conducive environment for the organism (felt or agar to hold moisture; attractants to encourage growth) and which facilitate creativity in participants (such as coloured felt to create dynamic substrates or novel modelling tools). Rather than following didactic delivery with prescribed outcomes, the workshops are intended to be open, generating unexpected results. I provide a framework – a conceptual scaffold - within which unforeseen outcomes can emerge.

Material thinking is important on several levels. Haptically engaging with materials opens up associative thinking (Csikszentmihalyi, 2010) and the agency of matter (Bolt, 2007), essential in all artistic research as “practice-based research is interrogatory in nature because the practitioner undergoes a hands on – or material – exploration of questions” (Vear, Candy and Edmonds, 2021 : 385). It is also fundamental to relational modelling where cognitive connections are made between systems operating across different realms and scales. Additionally, with the stated intention of raising the subjecthood of the slime mould in the minds of participants, a direct encounter is more likely to elicit potential empathy through a tangible entanglement with its corporeal form.

Creating experimental environments for slime mould navigation facilitates connections between biological, social, and technological systems at play. Frequently experiments created in petri-dishes for slime mould exploration echo a larger scale human exploration of the city. For example, in New York, mapping experiments were conducted in the Museum of Modern Art, observing and tracking the culture foraging behaviour of gallery visitors. Meanwhile, back in the lab, the slime mould was forming its own routes within a 3D model of the same suite of galleries (Figs 34-35). In Berlin, Munich and Amsterdam, the conditions for petri-dish cartographic experiments were established through a ‘slime mould subjective’ exploration of the city, with participants attuning to perceived attractants and repellants in the environment (remembering that the slime mould likes damp places and avoids light) (Figs 36-37, 42-43).

Engaging conceptually and haptically with an other-than-human epistemological and ontological world, workshops usually conclude with an invitation to take home a new ‘pet’, with slime mould care instructions given and ethical dimensions raised¹⁹. People are invited to post resulting behaviours observed during their own experiments on slimoco, the online network I founded at the start of my own empirical enquiry (*The Slime Mould Collective*, no date).

¹⁹ The question of responsibility is raised and discussed, regarding working with a living system which has no central nervous system, but clearly possesses agency and a highly attuned understanding of itself and its environment. Participants are invited to form their own ethics of care in working with the organism and taking home a new pet.

By working directly with *Physarum polycephalum*, the vitality and agency of the organism are manifest in its 'experimental body' and its unique spatiotemporal realities are revealed, albeit slowly by human terms²⁰. The performative aspects of the slime mould, and our asking something of it, present an 'intra-active dynamism of matter-energy' (Stengers, 1987) played out over differing timescales and enhanced through technological intervention (such as the use of time-lapse photography translating slime mould behaviours for human consumption). Working with the pulsing materiality of slime mould urges us to recognize it in the world. Taking notice, according to Heron (1996), is the first step to 'perceptual heed', discerning features from the ordinary "to intuit something about the patterning of the different entities in our world, the significant form of their interconnections, and about their modes of awareness." (ibid : 123). If we take notice we might also take responsibility.

3.3.3.2 Relational

In different cities, operating at shifting scales, phenomena were used as a basis for relational modelling, making connections between biological, social, and technological behaviour. Through conceptual and practical experiments, themes of urban rhythms and biosemiotics were conceptualized and manipulated, by employing the slime mould as a boundary object. Common to all projects was the exploration of networked systems across scalar dimensions (between organism and city), the examination of the shifting subjectivities between individual and collective action (responding to changes within the environment), and the development of a shared platform for challenging human-centric positions (to embrace the multitude of interconnections in our shared *ömwelt*). Speculation on other species-subjectivities was enacted through a form of *interspecies psychogeography*, taking 'ideas of an organism for a walk'. Playing *in mind* with concepts, mechanisms, and behaviours is a form of "empirical wandering", enacting "a strategy without finality" (Rheinberger, 1997 : 183). Through walking, observing, conversing, and improvising, participants re-frame perceptions of the city through the imagined sensory subjectivities of the slime mould.

²⁰ The average growth speed of *Physarum polycephalum* is around 1cm per hour, depending on temperature and humidity - not slow in biological terms, if you compare it to organisms such as lichen, but a challenge to impatient humans.

In Amsterdam, as part of the Open Set international Summer School, the focus was on the rhythms of the city, set within the context of the Bijlmer district, an urban area once envisioned as an architectural utopia and today one of the most vibrant and multicultural neighbourhoods in Amsterdam. *Fluid Rhythms: Urban Networks and Living Patterns*²¹, was a ten-day intensive programme of activities exploring “the potential of rhythm-led practices as common ground for research and artistic work” (*Open Set*, no date). Developing ideas from rhythm analysis research (Nevejan, Sefkatli and Cunningham, 2018) and the biosocial production of urban space (Lefebvre and Nicholson-Smith, 2013) the project took the quote ‘*The crowd is a body, the body is a crowd*’ (Lefebvre, 2004) as a starting point for thinking about the visible and invisible rhythms operating within and across the city infrastructures. The alternative design school was led by a curated group of practitioners and researchers who brought diverse expertise to the theme. I brought the slime mould to meet the locality of the Bijlmer neighbourhood and to use as a basis for situated, sensory, multispecies exploration of explicit and implicit oscillations in the environment (Figs 41-49). In addition to the usual progression through slime mould ‘assimilation’ (subject, material, model, embodied actions), we interrogated the laws of scale, as argued by theoretical physicist, Geoffrey West (2017), establishing comparative patterns of scaling across organisms, organisations, and cities. Exploring different positions (from remote sensing to close scrutiny) and perspectives (embracing human and nonhuman), we tested Bennett’s ideas of ‘vibrant matter’ (2010) through observing, interrogating and visualising the *actants* and *flows* present within the *assemblage* of the Bijlmer neighbourhood. Bennett’s observations on the invisible and ideological networks at play within energy infrastructures²² were noted through walking and mapping exercises and her texts were used as a basis for the creation of concrete poetry, reassembling fragments of philosophical thought into new formations. Ideas raised by the theorists were explored in practice through fieldwork and creative experimentation.

²¹ Open Set is a Dutch independent design education platform which promotes the social relevance of design and visual culture through a programme of labs, activities and networking opportunities. The curatorial team for Summer School *Fluid Rhythms* were Irina Shapiro, Mike Thompson and Noam Toran with contributions from leading artists, designers, chefs, musicians, writers, and a songbird master.

²² Chapter 2 of *Vibrant Matter* examines a major US electricity black out, Bennett using the incident to explore multiple positions and perspectives at play from human and nonhuman agents, to the political and ideological conditions of the infrastructures, and to the subjective needs of the electricity itself.

In Munich²³ the experiments took place in Maximiliansforum under the city's Altstadttring, a pedestrian subway nestled underneath a busy road intersection. It was dark, dingy and subterranean, with several routes out to the surface: a perfect location to think *about* and *with* slime mould. Here, inspired by biosemiotic processes²⁴ participants created a *stigmergic* intervention in the city with the potential to affect change in the behaviour of others (Figs 47-48). Stigmergy²⁵ is a process of indirect communication between agents through environmental actions whereby a trace left by one organism stimulates the actions of another. In this way, actions and reactions reinforce and build on each other, leading to the spontaneous emergence of coherent, seemingly coordinated events. Superorganism species, such as slime moulds, ants, and termites, communicate via such stigmergic mechanisms²⁶. This form of biosemiotic communication, which consciously or subconsciously affects the behaviour of others, operates through visual, physical, or chemical signals, forming a symbolic language understood by certain species. Theories of stigmergy have also been applied to multi-agent human-centric systems in relation to internet behaviour (Susnea, 2015), environmental trace-signals (Tummolini and Castelfranchi, 2007), and social epistemology (Marsh and Onof, 2008).

In Munich, taking these self-organising processes of behavioural affect as a basis for creative improvisation, we explored indirect communications within an urban environment, creating a form of cultural stigmergy to test human responses and reactions. Interventions took a variety of forms, with differing intentions. One group interrupted the flow of pedestrian traffic by placing orderly piles of leaves on the pavement and observed how people navigated around them²⁷. Another group tested the attention and curiosity of passing

²³ As contribution to the series *City Streaks*, invited by the "Arbeitskreis (Ak) Zur Resozialisierung von Gemeinem Grün" / "Working Group for the Resocialization of Common Green", a collective of artists and scientists: Rasso Rottenfusser, Susanne Schmitt, Anja Uhlig and Katharina Weishäupl.

²⁴ Biosemiotics (which translates from Greek as signs of life) is an interdisciplinary research framework investigating the myriad forms of communication and signification found in and between living systems. The concept was first developed by naturalist Jakob von Uexküll following his definitions of species subjective spatiotemporal 'umwelts'.

²⁵ The term stigmergy was first coined in 1959 by French zoologist, Pierre-Paul Grassé, in relation to termite coordination.

²⁶ For example, ants leave pheromone signals, slime moulds leave membranous trails, and termites leave mud balls, all of which communicate important information: about environmental conditions, indicating a location of a food source, a need to repair part of the nest, or an alarm signal warning of a predatory danger.

²⁷ Whilst not known for spontaneous coordination, humans often form directional lanes when walking along busy streets, by responding to subconscious cues.

pedestrians by placing small coloured markers in repeat patterns, located at different heights within the urban architecture²⁸. Stigmergic experiments were also enacted in Berlin, leaving chalk marks as ambiguous symbolic language, and in Amsterdam, intervening with existing street signage. As with other workshops, all stages of experimental development were enacted and discussed in an open and questioning manner, allowing for differing interpretations and associations to coalesce.

In Berlin, the interconnections of bio/techno/socio networks and their political significance were explored through GPS tracking in the streets surrounding Art Laboratory Berlin. Wandering as a collective body, following a few simple rules, individual movements were tracked via global satellite systems orbiting earth. Without any leader or destination in mind, and without speaking, a constant proximity was maintained in the group through visual connection. Viewing the surrounding territory as a self-organising nomadic information system, perspective switched between the dank decaying undergrowth of slime mould dwelling, the cosmopolitan streets of Berlin, and the technologised surveillance of the planet. The resulting film compositing the GPS trails revealed a slime mould like organism, individuated but cohesive in collectively navigating its environment (Figs 39-40) The street-scale mapping experiment complemented the petri dish map of slime mould exploration, the two scales in dialogue.

Across the different cities and through the various experiments, participants' positions shifted from observer to performer, intervener to commentator, individual to collective. Invited actions were purposefully (and playfully) disruptive, inviting people to break with the behavioural conventions of 'normal' city living. This encouraged participants to slow down and pay attention, to bring questions to bear in how the systems observed operate. Through such relational explorations, the interrelationships between differentiated networks were mediated through creative and playful methods, centred always around the subjective materiality of the slime mould and its sensing sensibilities.

²⁸ All physical interventions made into the cityscape comprised of temporary and/or biodegradable materials (including wooden sticks, a bag of fallen leaves, or a ball of string).

Within these transient communities multiple viewpoints can co-exist in dialogical arrangements, where multiple agendas, interpretations and intentions can coexist. Dialogical art practices, first articulated by classic pragmatists such as John Dewey (1995, 2005), are defined in the social conditions set for dialogue to take place. Professor of art history, Grant Kester, defines dialogical art as a shift “away from technical expertise or object-production and toward processes of intersubjective exchange” (2011 : 29), where materiality is not denied but rearticulated by individual interpretations. In the dialogical encounter difference can interplay without conflict, but with antagonism (Bishop, 2004), where the generative power of creative agency shifts away from the individual toward a larger social body. Whilst the move negates the individuated artist identity, it can still possess enormous critical and transformative power (Kester, 2011 : 138).

3.3.3.3 Behavioural

The behavioural properties of slime mould have been ever-present in the processes of co-enquiry. Running as a thread throughout *The Physarum Experiments* has been an embodied collective experiment inviting groups of humans to operate as an amoeboid organism, with individual decision-making replaced by an improvised form of collective action. The participatory experiment, *Being Slime Mould*, began in 2013 as accompaniment to the Biodesign exhibition in Rotterdam (Fig 50) and has subsequently coaxed many disparate groups of humans to attempt to operate as a mass supercell (Figs 51-55).

The fundamentals of this phenomenological experiment involved extracting the biological logic of slime mould and applying the behavioural rules to be enacted by a group of humans. One intention of the exercise was to put into practice a form of embodied cognition similar to that displayed by the organism, to ‘think with the body’ as part of a collective entity and to alter our usual modes of communication. The experiment puts into practice what Timothy Morton identifies as the distinction between ‘acting’ (with agency and autonomy, i.e. humans) and ‘behaving’ (from a biological impulse, i.e. nonhumans) (2018 : 111) by creating the opportunity to explore a multitude of phenomenological facets including motivation, intention, goal-directedness, communication, cooperation, decision-making, and (lack of) leadership. Through direct experience questions of individual agency, collective

intelligence, and the complexities of communication are explored with distinctions blurred between individual/collective, leader/follower, and action/reaction. It is an ‘absurd’²⁹ experiment, which generates emergent outcomes in the actions, interpretations and discussions that follow.

Being Slime Mould is discussed in detail in an invited essay for the peer-reviewed journal PUBLIC, in a special issue on Interspecies Communication (Barnett, 2019a) (Portfolio Published Text 2). The essay examines the participatory experiment as ontological speculation (or speculative ontology), drawing comparison to other contemporary existential enquiry, such as Charles Foster’s exploits contemplating life as a badger, fox or otter (2016) or Thomas Thwaites’ multidisciplinary investigation of ‘goatness’ (2016). Looking back to Thomas Nagel’s seminal 1936 essay speculating on the subjective reality of a bat (1974), the essay examines different disciplinary approaches to posing such ontological questions in practical and philosophical terms. The nature (and need) for anthropomorphism (Morton, 2018) is addressed, recognising the limitations of species-specific sensory realms (Uexküll, 1992). The knowing impossibility of the exercise is fully acknowledged, that we can never truly shift our *umwelt* to another form of existence, “since even if you intend not to be, there you are, a human, relating in whatever human way you are relating to whatever other lifeform.” (Morton, 2018 : 111). After all, Morton argues that a certain level of anthropomorphism is necessary to achieve a higher order of ecological awareness. Recognising the futility of ‘becoming other’ allows a certain freedom to simply entertain the idea and to engage in speculative curiosity about another subjective reality. It is the trying that counts.

The ‘rules’ of *Being Slime Mould* have evolved over time, each iteration adapting to meet new environments. This *reproduction* involves repetition and deviation, allowing methods to be tested in different contexts whilst also permitting a certain latitude. As it has migrated and morphed, the experiment has been framed differently, the shape-shifting organism becoming a malleable metaphoric model for collective action. For example: at a corporate

²⁹ Building on the well-grounded tradition of absurdism in artistic practice, recognizing that the world cannot be fully understood by reason alone and that meaning is insubstantial and incomplete. My work with slime mould has been referred to as absurd within a paper discussing the intra-active performativity of slime mould co-creation (Bates, 2015).

conference the slime mould became an exemplar case study for self-organisation and low hierarchy business models; at a somatic symposium it became a muse for reflecting on the true meaning of embodiment; and at a multispecies storytelling gathering it provided a relational model to transcend species hierarchies³⁰. Perhaps the most important unifying factor is that of intention, or lack of it. The experience of *Being Slime Mould* is purposefully purposeless, no direct goals are set, no time limit predefined. It is an intentionally aimless exploratory experiment, designed to observe what complex behaviours can emerge as a result of following just a few simple rules. As an experiential behavioural experiment, it is allowed to unfold, granting people a small window of time to simply *be*, as another ontological form. Following the experiment, observations and experiences are shared and interpretations are offered. Over the years, the duration of the experiment has ranged from five minutes to several days.

Most *Being Slime Mould* experiences are quite short lived (usually around 10-20 minutes) and I was interested to see how the embodied experiment could be pushed over an extended duration. Working with Swedish choreographer Emma Ribbing³¹ a piece of movement research was developed testing slime mould logic with a group of dancers, highly attuned to thinking with their bodies. Over several days in June 2017, we worked in an area of urban regeneration in Malmö, Sweden as a site for collective exploration. The dancers were given instructions drawn from the fundamental biological mechanisms of the slime mould (how the cells aggregate, how information is distributed across the cell structure, how it navigates its environment, and how it self-organises) and were then tasked to explore their surroundings as a connective body without any set goals. From this, a form of improvised choreography emerged creating “a whole panoply of relational-field effects” (Manning and Massumi, 2014 : 21).

³⁰ A full list of *Being Slime Mould* experiments conducted is available in the portfolio.

³¹ Emma Ribbing and I met at a scientific conference on *Collective Motion*, University of Uppsala, Sweden, invited by professor of applied mathematics and conference organiser, David Sumpter, to present non-scientific approaches to collective motion research.

The project, *Spatial Negotiations* (Fig 56-58), resulted in the production of two films, one artistically immersed in the emergent form of decentralised choreography, the other critically contextualising the intellectual and artistic intentions from our relative perspectives traversing visual art, performance, and pedagogy. Both films have been exhibited within galleries³² and also employed as a discussion prompt within urban regeneration meetings. In this context the movement research functions as a playful provocation on the priorities of regeneration agendas and the need to address multispecies perspectives. The exploration draws attention to the range of subjectivities (stakeholders) beyond our immediate horizon, raises questions and focuses attention - a subtle attempt to influence process and policymaking in urban regeneration scenarios.

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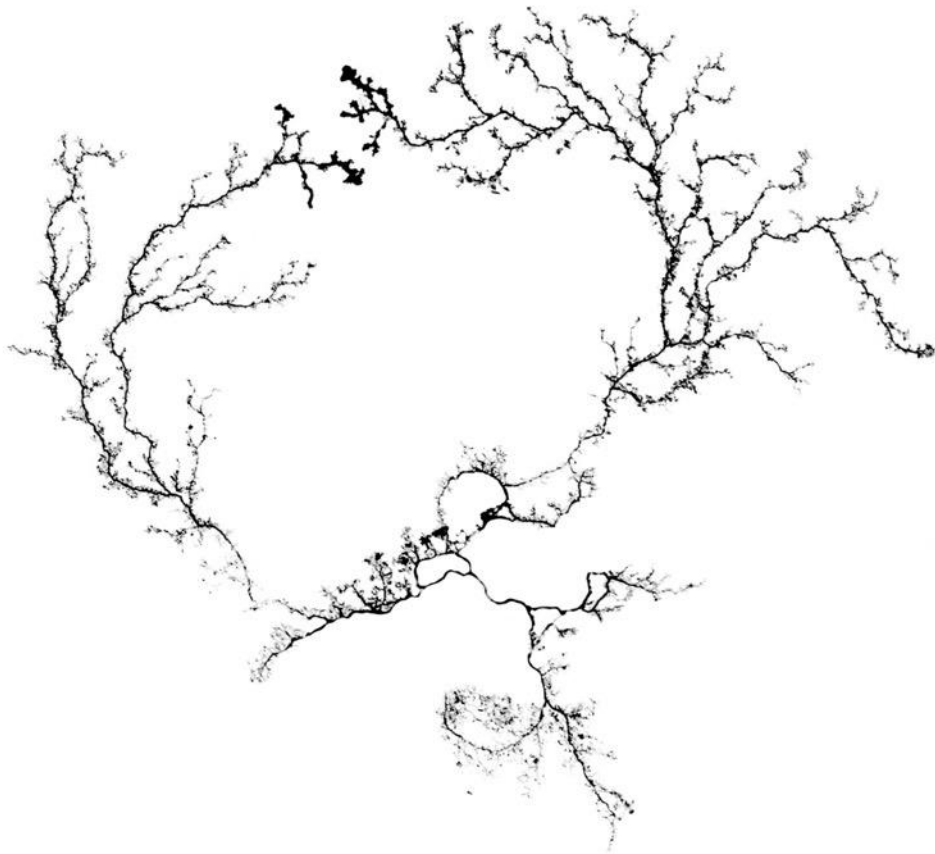
Across all the modes of co-enquiry presented - whether material exploration, relational mapping exercises, urban meanderings, stigmergic improvisation, or embodied actions – the intention has fundamentally been to raise interest in the organism as a subject, a medium, and as a metaphorical model; to expand my own investigations by inviting others to join and bring their own curiosity and questions. In this way, the slime mould's function as a boundary object collectively produces a body of knowledge which is shared yet differentiated, with each person tuning in and interpreting events from a unique perspective. Knowledge is generated through material, relational, and behavioural modes of enquiry within an experimental system that is fluid and open, creating myriad definitions, associations, and speculations. Knowledge is held within the collective body of the participating humans as it is held within the body of the organism, as a flow of information nodes shuttling around in a dynamic network.

This commentary presents published works made *with*, *of* and *about* the slime mould *Physarum polycephalum*. The mode of art-making presented is one that is co-constituted with other organisms, through models of co-enquiry that are inherently multi-species and

³² *Spatial Negotiations* has been exhibited at Tallinn Architectural Biennale (2017), Nonhuman Agents, Art Laboratory Berlin (2017), plus several Swedish exhibitions and festivals including Malmö Moderna Museum.

transcend disciplinary boundaries. Tangible artistic outputs include the construction of environmental arenas for slime mould exploration, time-lapse studies, sculptural objects, print and digital artworks and interactive installations. Transient artistic outputs take the form of workshops, collective experiments, participatory practices, and embodied actions. The two elements are reciprocal, each informing and influencing the other, creating feedback loops between the working methods with slime mould and with human collaborators. Through the artworks the organism reveals itself, and its inherent characteristics and capabilities, via my mediation, granting access to a glimpse of slime mould subjecthood. As Shaviro notes, "For our part we can only grasp the slime mould's experience partially and indirectly, by its actual behavior, and by the traces of evidence that it leaves behind." (2016 : 215). These traces of evidence are also present in the portfolio of published works, representing a diversity of artistic research methods which involve both 'making things' and 'making things happen', collectively produced through encounters created between human and nonhuman actors.

4. Conclusions: Assembling Subjectivities



The Physarum Experiments: Growth Studies #4 Recognition

Artists whose work involves the direct transformation of living organisms or the creation of new life ought to realize that their efforts no longer take place in the well defined domain of objecthood—but rather in the more complex and fluid zone of subjecthood. Subjects are alive, free, and autonomous.

(Kac, 2007: 12)

The knowledge produced through these complex interweavings between organisms and environments is fundamentally sympoetic – collectively produced. The myriad artworks, exhibitions, events, experiments, talks, workshops, conversations, actions, and texts which form the enquiry of *The Physarum Experiments* have been created through a recursive system of provocations, invitations, and interruptions – with human and nonhuman agents. As Donna Haraway notes, “Sympoesis is a carrier bag for ongoingness, a yoke for becoming with” (Haraway, 2016 : 125). Whilst I instigate the actions and create the conditions for ‘something to happen’, the work is co-created with thousands of slime mould nuclei sharing a cell membrane intra-acting with thousands of humans sharing a common curiosity.

As is elucidated through the commentary, the trajectories of enquiry have operated distinctly and cooperatively in the development of research frameworks, weaving between different knowledge systems in the construction of artworks, narratives, and experiences. My approach constructs a unique conceptual scaffold where intuition, observation, and insight find articulation through the iterative and recursive feedback loops of artistic research, building knowledge cumulatively. Here, the research framework is implicit in the practice, unfolding through the layers of experimentation within the system. There is a constant triangulation between the material, relational, and behavioural characteristics navigating around the slime mould, shifting focus between phenomena, perceptions, concepts, and actions. Within such a fluid experimental system “triangulation helps us to get a ‘fix’ on something in order to understand more fully the complexity of issues by examining them from different perspectives, and generating data in different ways by using different methods.” (Gray and Malins, 2004 : 121). Within this body of living systems artistic research, triangulation refers to the multi/inter/a disciplinary mixing of methods, modes, and interpretations which amalgamate around the organism (as subject of curiosity) and central questions relating to the many layers of intellectual association (the polycephalic readings of the organism). Triangulation also relates to our relative positioning and how we engage with

the subject – at individual, group, environment level – the interrelationships between the dimensions creating an ecology of practice.

The knowledge produced within such an interspecies ecosystem stems from the construction of conditions that elicit the potentiality for the production of knowledge in others. The organism, as an epistemic thing, carries knowledge in its pulsing, creeping body, made manifest to human senses through technological, aesthetic, and behavioural intervention. The human creates a network of relational connections with the organism (in material and representational form) bringing prior knowledge, disciplinary perspective, and individual intrigue into the encounter. Knowledge production within this system is distributed and emergent, with multiple interconnected processes creating feedback loops between understandings of the organism and experimental findings. The question-generating machine that is slime mould, and its related systems of research, work within the dynamics, apparatuses, and behaviours of the system. Additionally, contextual, situated and community knowledges bring differentiated perspectives into dialogue with each other, the *epistemic object* creating *epistemic events* (White, 2013). Shifting between explicit and implicit processes of critical and creative enquiry, knowledge is generated (individually) and co-generated (collectively) by all agents operating within the experimental system, defined as:

- Knowledge *with* the organism – that which is revealed by the slime mould in its representations, renderings and readings and the visual storytelling that emerges from empirical studies (found in the time-lapse films and other artworks);
- Knowledge *through* the organism – the associative, connective tissue that conceptually links network thinking between scalar dimensions and in/tangible matter; the speculative thinking that happens in material, relational, and behavioural exploration (found in the systems of co-enquiry and collective experimentation);
- Knowledge *of* the organism – the retrospective articulation of intentions, methods, and outcomes which recognises pattern, finds meaning and locates the work within wider contextual cultures of enquiry (found in the critical and reflective writing).

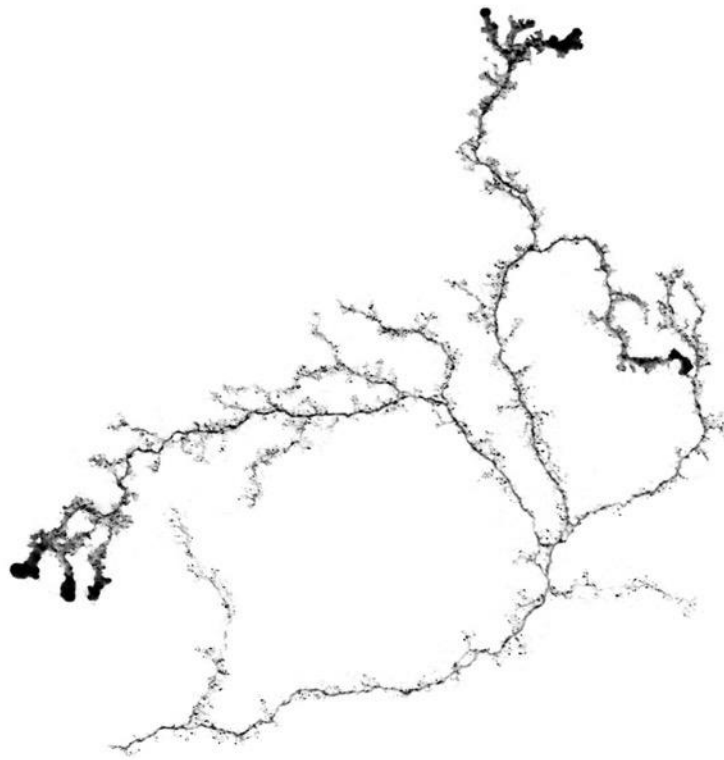
Movement is an important facet throughout: movement between knowledge modes, allowing for deeper insight through the interrelationships between presentational, practical, propositional, and experiential knowledge (Heron, 1996); movement between disciplinary domains, allowing for more complex hybridised enquiry merging art, science, and philosophy; and movement between scales, from examining the subjective life of a forest dwelling organism to planetary information systems. Like the slime mould, the curiosity-driven, practice-led system of enquiry has been dynamic and exploratory. The core root of the migratory practice evident within *The Physarum Experiments* pertains to the nomadic concepts embodied within the organism and its relational associations – raising onto-epistemological questions of our understanding of communication, coordination, self-organisation, information distribution, cognition, intelligence, sentience, decentralisation, network theory, systems thinking, computation, and emergence ... for example. After all, *Physarum polycephalum* is an amoeboid encyclopaedia for posthuman scholarship. The interpretive flexibility of the organism makes it an exemplar boundary object, operating within an open space between disciplinary divides, conveying interpretation, symbolism, and signification.

The model organism as a boundary object is a carrier of nomadic concepts (Stengers, 1987 : Braidotti, 2011) which shift meaning through their migration from one disciplinary realm to another. Their plasticity and adaptability “depends on their cultural embedding: a concept in one discipline may operate differently than in another, making travel from one milieu to another a factor of modification.” (Surman, Stráner and Haslinger, 2014 : 2). The model organism outside of the practice of the life sciences shifts its identity from a purely *epistemic* thing to an *ontologic* thing, taking with it an abundance of experience, agency, and effect. It permits us to tell stories, to dwell in awe and wonder, to create (and destroy) worlds, and to construct relational narratives. The act of *worlding*, the process of “theorizing and storytelling that is rooted in the historical materialities of meetings between humans and nonhumans”, encourages us to “inhabit new ecologies” (Tsing *et al.*, 2017 : 23) and imagine new possibilities.

What these characteristics amount to is a relational unfolding of subjecthood in the model organism, through the creative act of making with, thinking with, playing with, being,

becoming, and doing with others. Through *The Physarum Experiments* I have created experimental systems of co-experimentation - *assemblages* of apparatuses, methods, and processes – which have evolved alongside developments in critical theory, philosophical literature, and artistic research to challenge our dominant humancentric tendencies and argue for radical shifts in our thinking and acting in the world. Like Haraway, “I am committed to art science worldings as sympoietic practices for living on a damaged planet” (2016 : 67). *Thinking with* slime mould as a malleable model grants us an opportunity to reconsider our frameworks for intra-relations with the myriad of kin species in our shared habitat and challenges the perceived status of ‘lower’ organisms. The contribution to knowledge pertains to the complex interweaving of species subjectivities, between the sensory worlds of slime moulds and humans, and the multiple interspecies interactions urgently required for the creation of more attuned and reciprocal relationships.

5. Afterword: Slime Mould's Ongoing Cultural Moment



The Physarum Experiments: Growth Studies #5 Intention

Slime molds invite us to look with wonder at what is small and overlooked. Perhaps they can help dismantle our delusions of human exceptionalism—with their absurd hidden ethereal beauty. They can dissolve the boundaries we pretend exist—with their remarkable metamorphoses. They can challenge our stagnant cultural notions—with their existence as both collective and individual.

(Jones 2023)

The Physarum Experiments is an ongoing critical and creative enquiry examining our relations with and recognition of other forms of intelligent life. Whilst my model organism of choice possesses particular peculiarities which render it a novel and engaging subject - a material, relational, and behavioural model - the research centres on a wider paradigm shift in ecological and posthuman thought, as we respond to ever-increasing environmental crises and urgent planetary needs.

Since the research presented has been undertaken, other kin species have been ‘*thought with*’, organisms employed to help us better navigate the complexity and precarity of our times. For example, anthropologist Anna Lowenhaupt Tsing’s book, *The Mushroom at the End of the World* (2017), examines the failings of the human addiction to progress through the lens of the Matsutake mushroom. Traversing the territories of ecology, trade, and cultural history the mushroom is employed as a vehicle to examine “the relationship between capitalist destruction and collaborative survival within multispecies landscapes”³³. Fungal complexities are also taken up by biologist Merlin Sheldrake in *Entangled Life* (2020), which sets out to “enjoy the ambiguities that fungi present” (2020 : 15), navigating many interconnected threads of a neglected storytelling subject. As kin species, slime moulds are naturally cited, in relation to their innately impressive biological repertoire and ecological contribution, as well as to their indistinct individual/collective identity and their ambiguous sexuality. Both authors weave narratives of interspecies interrelationships, past and present, and argue for a radical change in how we think about and enact with multispecies ecosystems. For Sheldrake, embracing these unsung heroes of the natural (and cultural) world can create a perspective shift as “some of the vexed hierarchies that underpin

³³ According to the book jacket blurb.

modern thought start to soften. As they soften, our ruinous attitudes towards the more-than-human world may start to change.” (ibid : 17).

Slime moulds are highlighted in other recent publications. In journalist Susanne Wedlich’s treatise, *Slime: a natural history* (2021), human sensibilities of slimy matter are examined in a broad exploration of natural history, popular culture, and material relations. Slime moulds also feature throughout James Bridle’s *Ways of Being: beyond human intelligence*, which proposes an ecology of technology (2022). Bridle creates links between matter and energy, between things and beings, and between technological and biological intelligences. For them, “slime moulds have, under close examination, taken on a kind of weird, communal individuality, and like the discipline of cybernetics they continually refuse to settle into a new domain.” (ibid : 192). Their ambiguity defies easy classification, pertaining to “radical otherness as the driver of adaptability” (ibid : 215) and their decentralized distributed intelligence provides an exemplar model for a paradigm shift in thinking about “technologies of cooperation, mutual empowerment and liberation [rather than] technologies of control and domination” (ibid : 213).

Evidently, slime moulds continue to have “a cultural moment” (Jones, 2023) as more people are drawn into a “radical noticing” (Heron, 1996) of the organism’s multiplicitous capabilities. In a recent essay for *Emergence Magazine*, journalist Lucy Jones forages through the undergrowth to uncover stories of slime mould wonder, holding up the organism as a symbol of hope for humanity to dismantle the straitjacket distinctions we impose on life, which limit possibilities and understanding.³⁴

We think we have mastered the natural world, yet we don’t know how a slime without an apparent brain can conduct itself intelligently. We think we can bend the Earth to our will, but we know barely anything about microorganisms. We think we are in charge, yet we know next to nothing about the slime around us that reigned on Earth for a billion or more years. (Jones, 2023)

³⁴ The article cites my artistic work alongside the influence of slime moulds on Octavia Butler’s science fiction series, *Exogenesis* which characterises a hybrid human/organism interbreeding.

These publications – all dated after the timeframe of the published work presented in this thesis – demonstrate an ever-growing interest in the subjecthood of slime mould specifically and, more generally, an ever-increasing urgency for noticing, understanding, and engaging meaningfully with other forms of intelligent life, with all their ambiguities and muddy boundaries. It is now well over a decade since I began *thinking with* the single-celled intelligence of the slime mould, *Physarum polycephalum*, a journey which has taken me on many intellectual and creative journeys. The organism continues to intrigue and surprise. Whilst I'm in reflective mode, writing this, my slime mould sleeps, many dried dormant potentialities waiting to be awoken (upon a sprinkling of water) to resume their 'empirical wandering'.

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Part B) Portfolio of Published Work

The Physarum Experiments
2009-2019

B1: Material Investigations

The portfolio refers to a number of moving image artworks, predominantly a series of time-lapse films made with the slime mould *Physarum polycephalum*.

Please watch this short compilation film as introduction to the work (3 mins duration):

<https://youtu.be/b--9igdVj0>



Fig 01: The many-headed slime mould, *Physarum polycephalum*
Photo © Heather Barnett

Comprising thousands, often millions, of individual nuclei, all operating as one single entity, the slime mould is considered a superorganism – a collective organization of individual elements working in highly coordinated ways.

It is therefore little surprise that, outside of its natural habitat, the slime mould has become a valuable model organism, serving diverse fields of enquiry, from biophysics to computer science, from urban planning to philosophy and from material science to music and art. In laboratories and studios across the globe, researchers are asking questions of the slime mould, seeking to better understand how such a simple organism can achieve such complex tasks.

(Barnett, 2023 : 201)

Early experiments



Fig 02: Early experiments and observed behaviours (from top): dietary experiments with desiccated insects; observing nomadic tendencies as the slime mould escapes one petri dish and enters another in search of novelty; early experiments with felt substrate dried out, triggering a transition into fruiting bodies.

Photos © Heather Barnett

[The research presented] examines the behaviours of this intriguing organism as mediated through a series of time-lapse studies designed to draw out inherent processes of life. Responding to given interventions – a series of invitations and interruptions utilizing known attractants and repellents – a performative stimulus/response emerges. The imaging technologies employed amplify the biological world of the slime mould to human spatio-temporal scale. The intention of the studies is to reveal the underlying processes at play within this fascinating and beautiful organism and, through the aesthetic and technological devices employed, to entice other humans to observe and take note.

(Barnett, 2022 : 223)

Time-lapse Studies and Films

Between 2009 and 2019 I created over 30 time-lapse studies and short films, working with the slime mould, *Physarum polycephalum*, drawing out the inherent characteristics of this single-celled intelligent organism.

The outputs from the studio experimentation have been exhibited internationally (listed on p 42) and made available online to maximise audience reach and open them up for wide interpretation and reappropriation (discussed in Section 3.5 of the commentary).

The films are published online on a YouTube channel (with viewings in excess of 400,000) and on slimoco (The Slime Mould Collective), an online network I established in 2009 to connect with other curious researchers and practitioners.

The films can be viewed online:

<http://heatherbarnett.co.uk/work/the-physarum-experiments/>

<https://www.youtube.com/playlist?list=PL052BA2BC570A3852>

<http://slimoco.ning.com/>

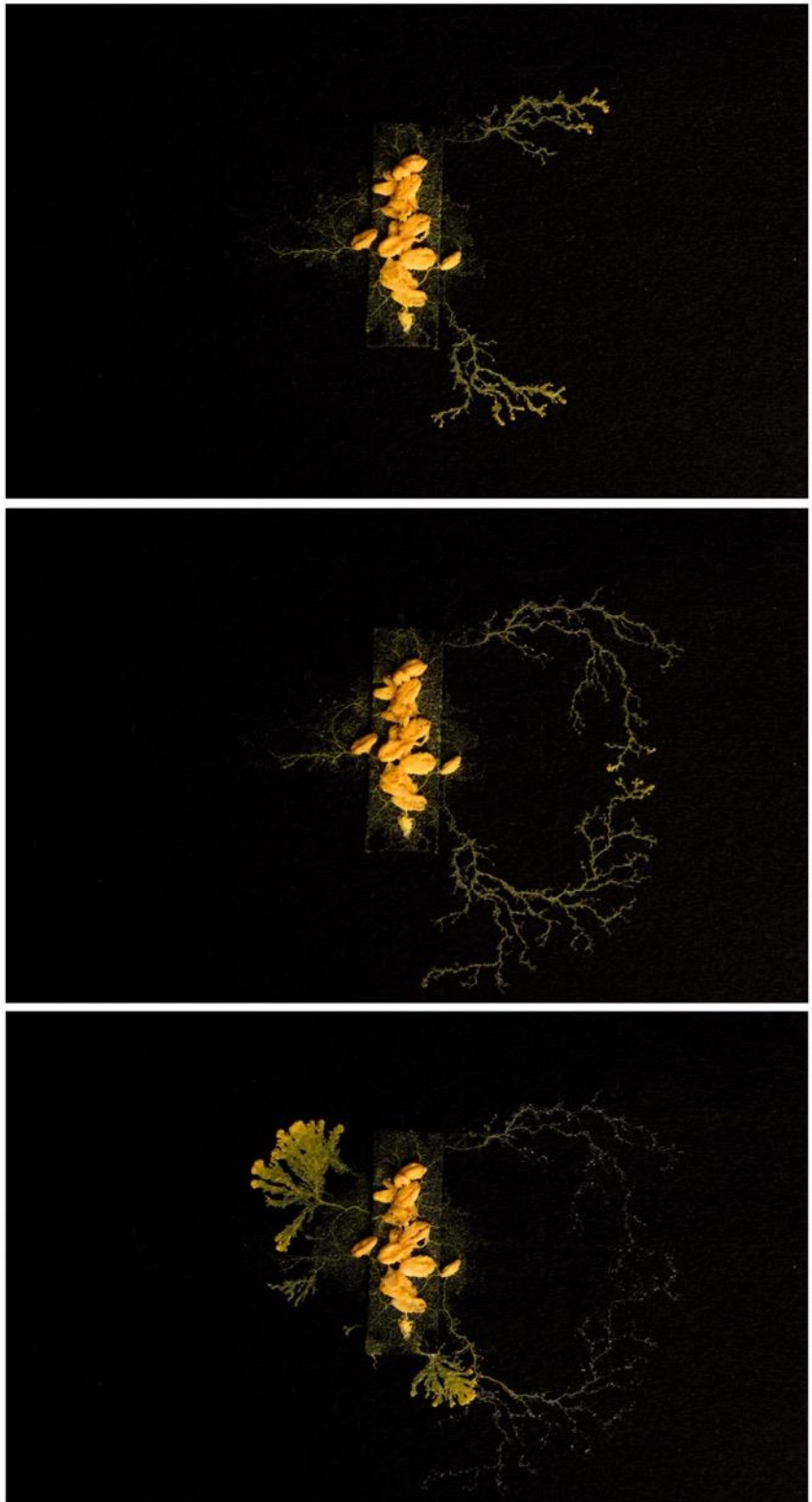


Fig 03: Film stills from *Study No.011: Points of Recognition* (2009) by Heather Barnett showing (from the top): simultaneous growth trajectories; a meeting point of self-recognition (allorecognition); resulting in a dramatic change in direction of growth. [HD video: duration 03:36] View film at: <https://youtu.be/Lc9Y4M5vvtE>

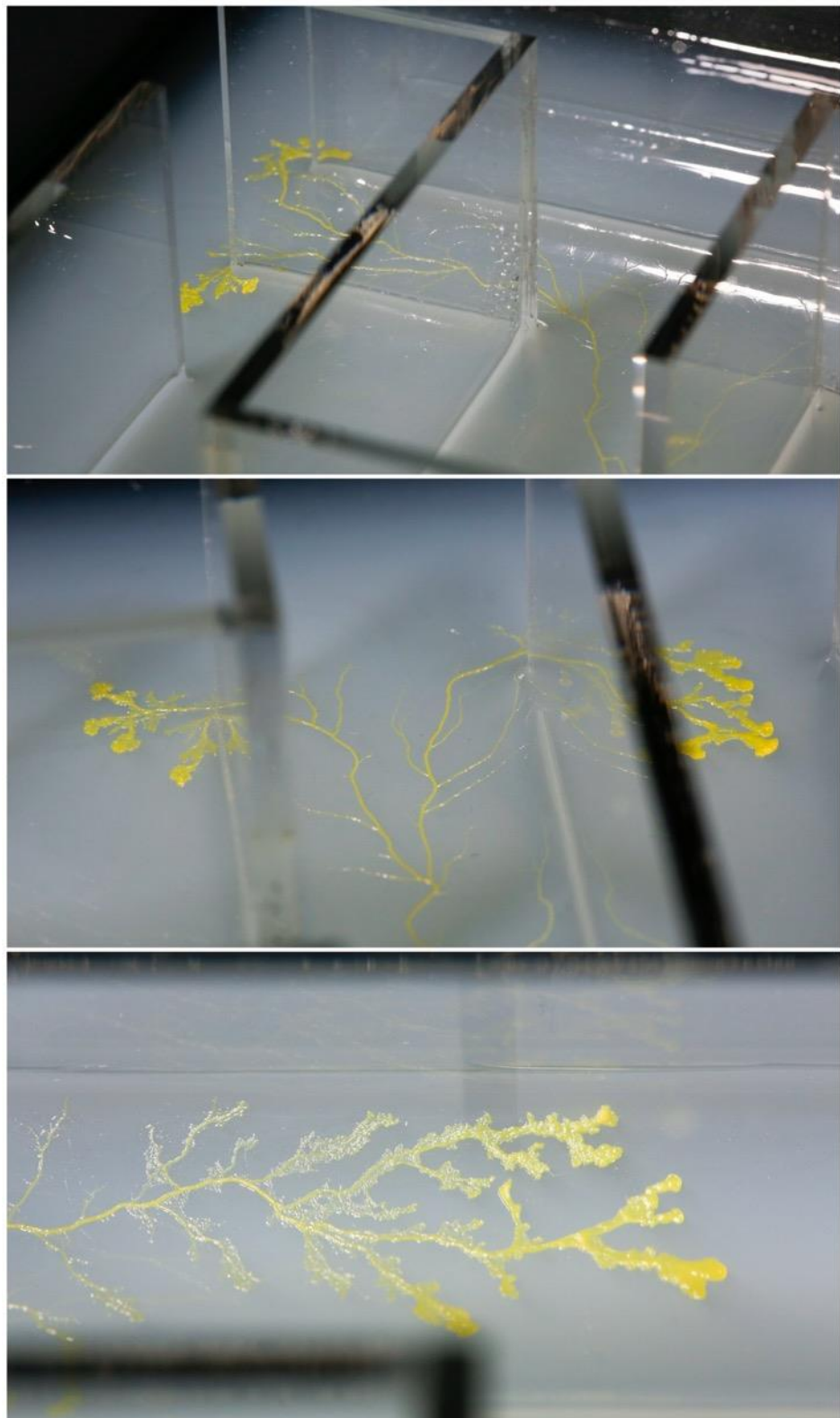


Fig 04: Film stills from *Study No.019: The Maze (2013)* by Heather Barnett depicting the navigational decision making of the slime mould as it navigates a maze, choosing when to split into two to explore multiple directions simultaneously. [HD video: duration 03:14] View film at: <https://youtu.be/b--9igdJVj0>

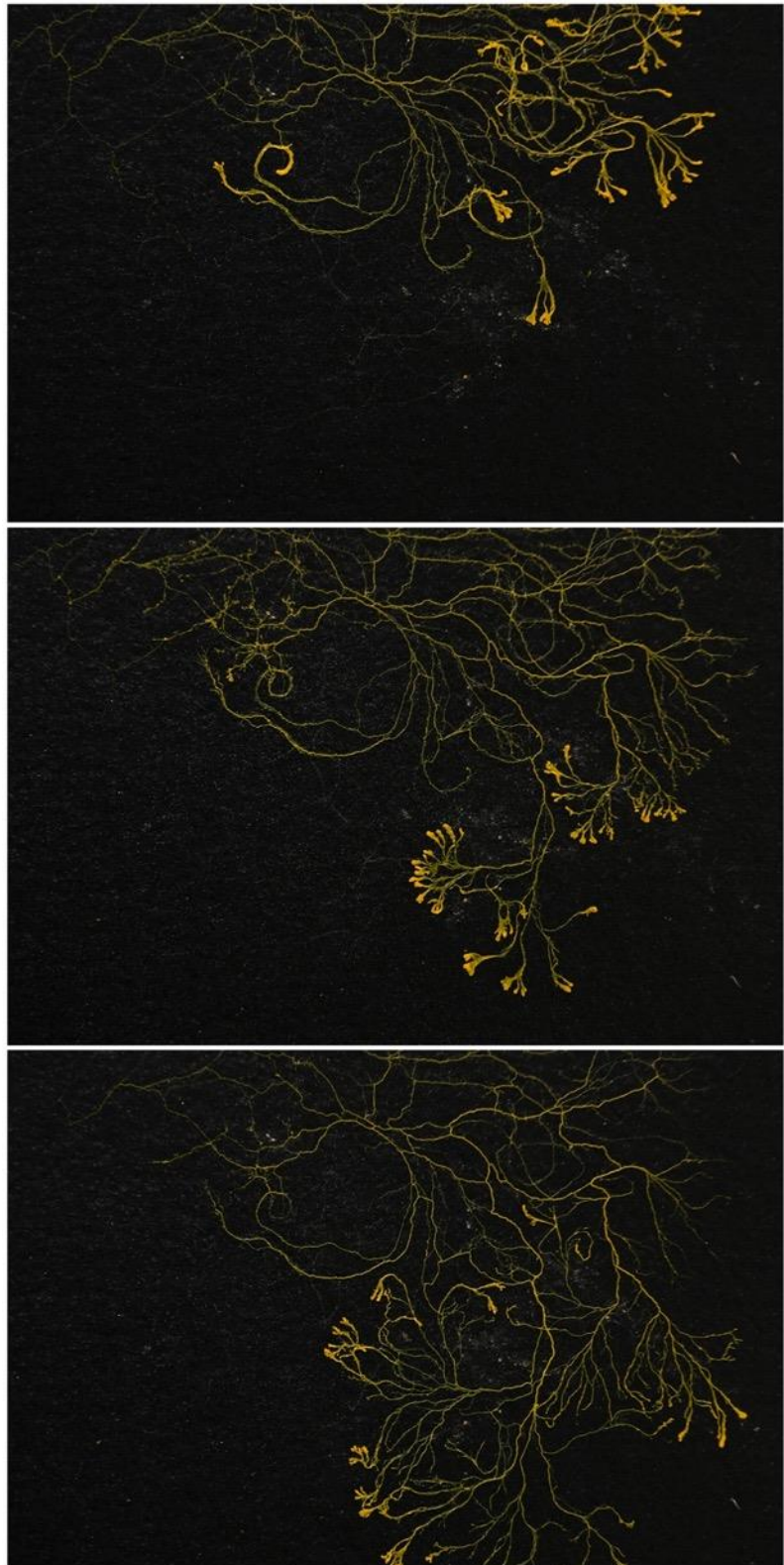
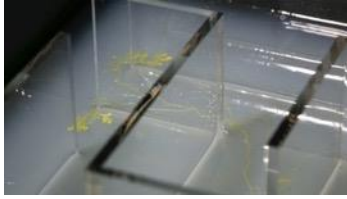


Fig 05: Film stills from *Study No.022: Starvation Fireworks (2016)* by Heather Barnett revealing surprising growth trajectories when food is removed from the environment. [HD video: duration 01:34] View film at: <https://youtu.be/5tYKYpQzu6E>



Fig 06: Film stills from *Study No.024: Interspecies Encounter (2016)* by Heather Barnett depicting the meeting between two species of slime mould, *Physarum polycephalum* and *Badhamia* and the resulting strategies of attack, defense and avoidance. [HD video: duration 02:38] View film at: <https://youtu.be/cbEirySHYXc>



Study No.019: The Maze

Inspired by the maze solving capabilities of slime mould as described in the seminal scientific study which demonstrated primitive intelligence (Nakagaki, 2000), I created a 3-dimensional version of the maze and introduced the slime mould. Rather than repeat the scientific study, the experiment was intended to reference the paper and its resulting conclusions as an homage, my replica scaling up and elevating the experimental terrain. As the slime mould navigated the maze in search of nutrients, the decision-making mechanisms within the body of the organism were revealed on each environmental encounter. Here the scientific paper forms a springboard for improvised exploration.



Study No.022: Starvation Fireworks

Inspired by the knowledge that the slime mould was able to detect food through chemical transmission through air molecules or substrate (Masui et al. 2018), I was curious as to how it would respond to the sudden change in the availability of resources. I removed all food from the environment midway through an observed experiment. The resulting trajectories showed a dramatic display of simultaneous growth trajectories in response to the sudden disappearance of food. Here, the state of relative hunger/satiation became part of the experimental system - balancing hunger states is a key element to slime mould experimental design and 'performance' and indicative of the success of the anticipated outcomes. Generally, if given too much food it will merely stop and eat and not display curious nomadic behaviours.



Study No.024: Interspecies Encounter

This experiment involved the introduction of two species of slime mould: *Physarum polycephalum* and a Danish cousin, *Badhamia*. Whilst they possess similar morphology and general growth behaviour, their character is distinct. As the two organisms approached one another, one species formed a dominant pulsing wall of attack, whilst the other took evasive action, splitting into smaller parts. Some parts of the cell retreated, whilst one part closest to the attack hid behind a porridge oat circumnavigating the invading organism as it passed by. As it navigates its environment the slime mould is making multiple complex decisions, trying to calculate a route with maximum resource pay off but with minimal risk, interpretations supported by the scientific literature analyzing variable cost/benefit trade-offs (Beekman and Latty 2011, 2015; Reid et al. 2013, 2016).

The intention is not merely to depict the slime mould as a biological object of curiosity, but to draw out its inherent behaviours as a subject and draw in the observer to meet another species halfway. The time-lapse process is intended to mediate between the relative physiological limits of perception and draw out that which cannot ordinarily be seen in human time and space. To draw out is to entice, to lure something out, to tease into being. A process of gradual extraction, drawing out is to prolong, to lengthen the time, implying a pulling of threads or of information. In human terms, it can mean to induce someone to speak openly, to reveal true feelings. In slime mould terms, it means to amplify processes of life which lie beyond our perceptual grasp and to scale up the organism (literally and metaphorically) in the hope of creating a relational space between two radically different spatiotemporal worlds.

(Barnett, 2023 : 215)

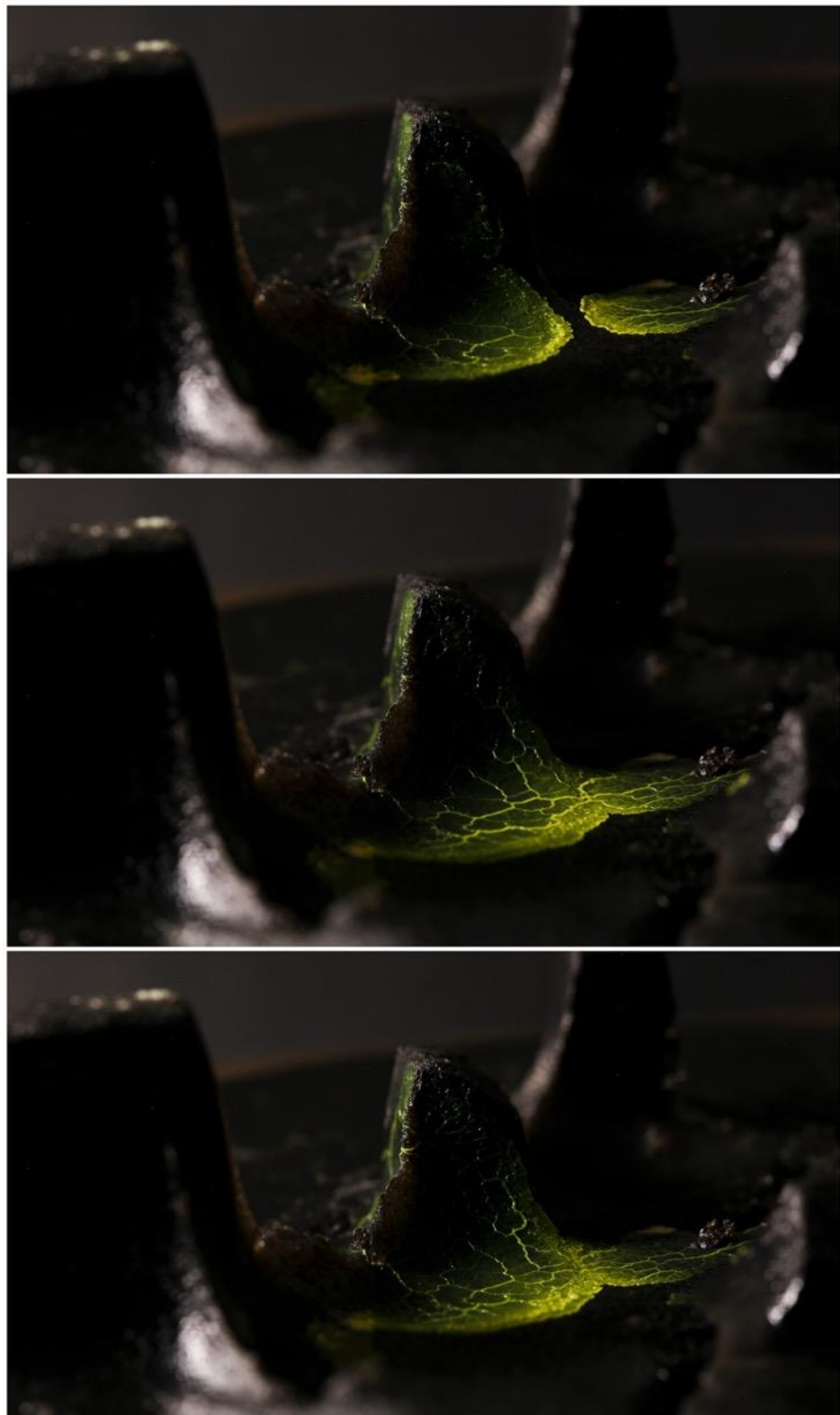


Fig 07: Film stills from *Study No.026: Intraspecies Fusion (2018)* by Heather Barnett depicting the moment when two genetically identical slime moulds meet and fuse, exchanging matter, memory and environmental information. [HD video: duration 02:46] View film at: <https://youtu.be/wSCZSBcZND>

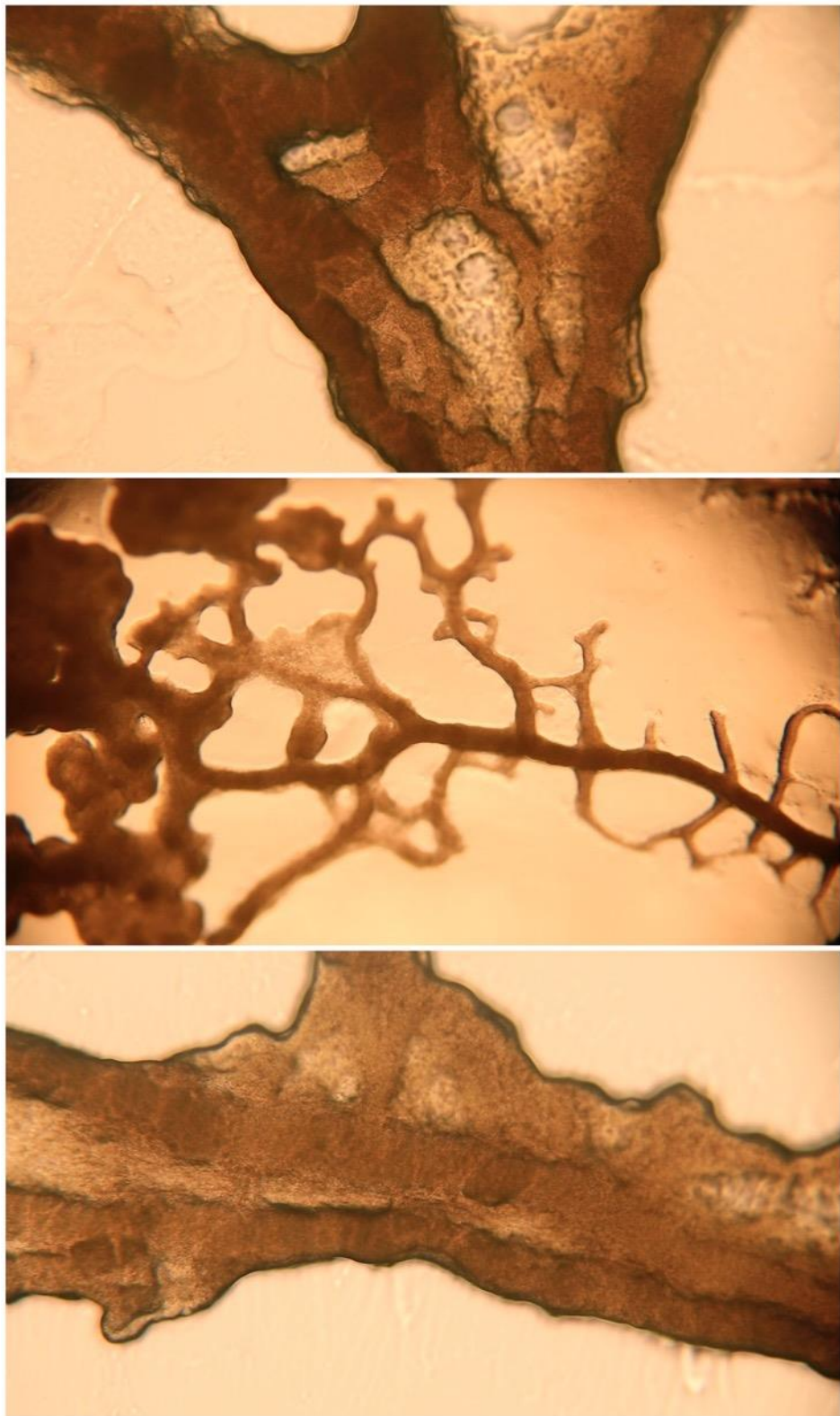


Fig 08: Film stills from *Study No.020: Streaming* (2013) by Heather Barnett
Microscopy footage showing protoplasmic streaming, the internal pulsing mechanism that distributes nutrients and chemical information around the dynamic shape-shifting morphology of the slime mould.
[HD video: duration 02:43] View film at: <https://youtu.be/kuaF5g3RnBo>



Fig 09: Memory trails: the trails of extracellular matter left behind the slime mould as it explores, leaving a chemical trace in the environment indicating where it's been – a stigmergic form of indirect communication.
[HD digital photograph. Photos © Heather Barnett]



Fig 10a: Film still from *Resilient Topographies: the peninsula of Paljassaare* by Heather Barnett (working with ecologicstudio) showing the slime mould traversing the 'moisture landscape' of the peninsula.

On Paljassaare local bird populations and microorganisms living in the waste-water treatment centres compete for resources, with each other, and with human priorities and values. Data sets from these species-specific subjectivities were gathered and reimagined as moisture maps, drawing on their individual subjectivities. Paljassaare was thus remapped as an information landscape, with data sets taken from the site translated as 3D printed topographies, and then handed to me to reanimate with a living information-distributing system, the slime mould *Physarum polycephalum*. I coated the topography in coloured agar gel (to represent land or water) and introduced the slime mould, filming it as it navigated its new terrain and computed its surroundings.

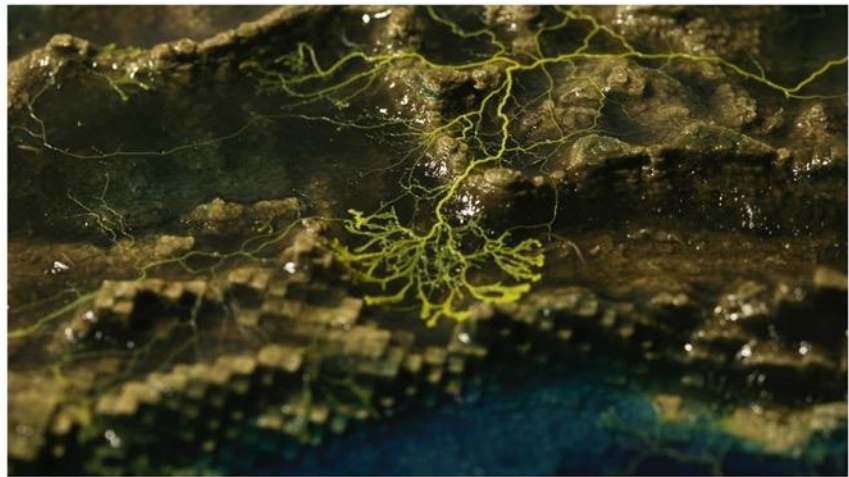


Fig 10b: Film stills from *Resilient Topographies: the peninsula of Paljassaare* by Heather Barnett showing the slime mould traversing the 'moisture landscape' of the peninsula, contouring around the data features and keeping close to the areas of maximum moisture, its preferred habit. Film made in collaboration with ecoLogicStudio for BioTallinn, Tallinn Archetectoral Bienalle 2017 [HD video: duration 02:44] View film at: <https://youtu.be/qRzRXUTkgP0>

The intention of this reciprocal interplay – between slime mould and human – is an invitation for an aesthetic pondering on disparate life forces and modes of existence. Whilst we can only ‘grasp the slime mold’s experience partially and indirectly, by its actual behavior and by the traces of evidence that it leaves behind’ (Shaviro 2016: 215), the temporal amplification offered by technological mediation permits access to some tacit understanding of the modes of decision making which occur within the organism as it operates in constant dialogue with its Umwelt. This relational encounter may encourage us to challenge our own definitions of intelligence, where human-centric (and therefore neuronally biased) positions are called into question by an embodied and chemically sensitive form of knowing.

(Barnett, 2023 : 215)

Experimental Systems

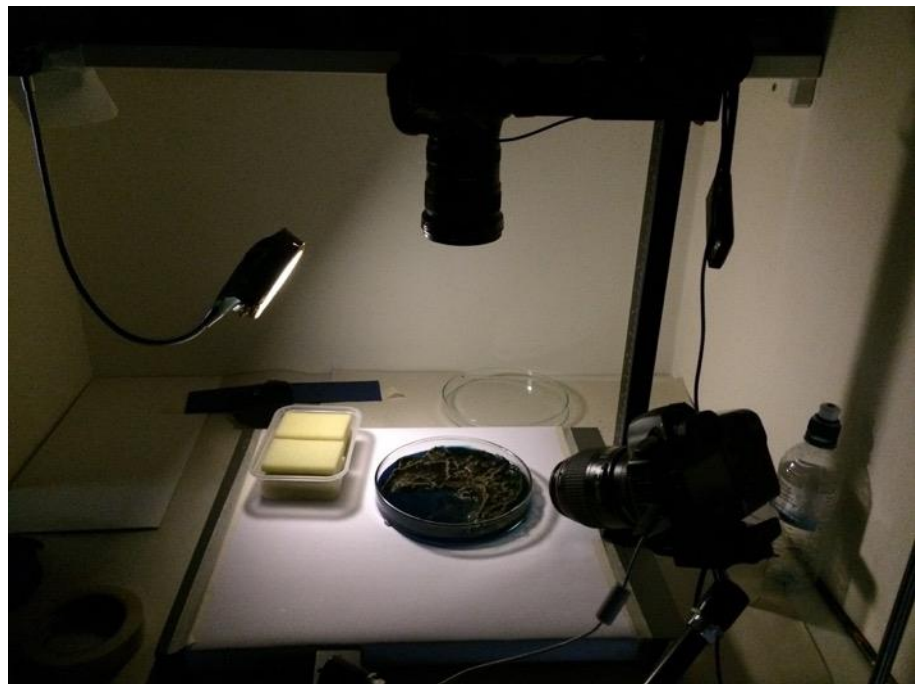


Fig 11: Experimental apparatus in the studio: (top) a dark tent provides a controlled environment to photograph slime mould growth; microscope for viewing protoplasmic streaming. (bottom) Time-lapse set up for *Resilient Topographies*, in the dark tent: apparatus includes two cameras with macro and wide-angle lenses, low level LED light, petri dish with damp substrate and slime mould, humidity sponges. Photos © Heather Barnett



Fig 12: Growth substrates. Slime mould requires a moist substrate to grow. From top: cast agar (coloured black with squid ink powder) providing an abstract cityscape for *Study No: 024 Intraspecies Encounters*; laser cut wooden contour map coated with an agar pour providing an abstract terrain (test for *Resilient Topographies*); laser cut acrylic map of Hackney Wick on black agar for a living artwork at *Crowd Control* exhibition at arebyte gallery. Photos © Heather Barnett



Fig 13: Culinary experiments with attractants and repellents. From top: testing growth behaviour in response to nutrient rich or hostile environments; dyeing oat flakes with natural food colouring to affect pigment colour; stock-piling different growth media for batch experiments. Photos © Heather Barnett



Fig 14: Slime mould farming. The experimental system requires stocks of healthy and hungry slime mould. From top: plating out slime mold in petri dishes in a shoe box to limit light contamination; pouring multiple agar plates for experimentation; the nomadic slime mould escaping having exhausted resources in the dish. Photos © Heather Barnett

Other Artworks

Additional artworks are included in the portfolio to illustrate the range of media and techniques employed in working with the organism.

The Growth Studies capture single significant moments in the navigational behaviour of the slime mould. As the organism explores new territory, it quickly learns where it has been, when it meets itself and where it is yet to venture.

These single frames derive from *The Physarum Experiments, Study No: 011*

Growth Study 1: Amplification

Growth Study 2: Cooperation

Growth Study 3: Elaboration

Growth Study 4: Recognition

Growth Study 5: Intention

These images illustrate the start of each section of the thesis commentary.



Fig 15: *The Growth Studies* by Heather Barnett. Installation view at Cut/Paste/Grow, Observatory, Brooklyn, 2013

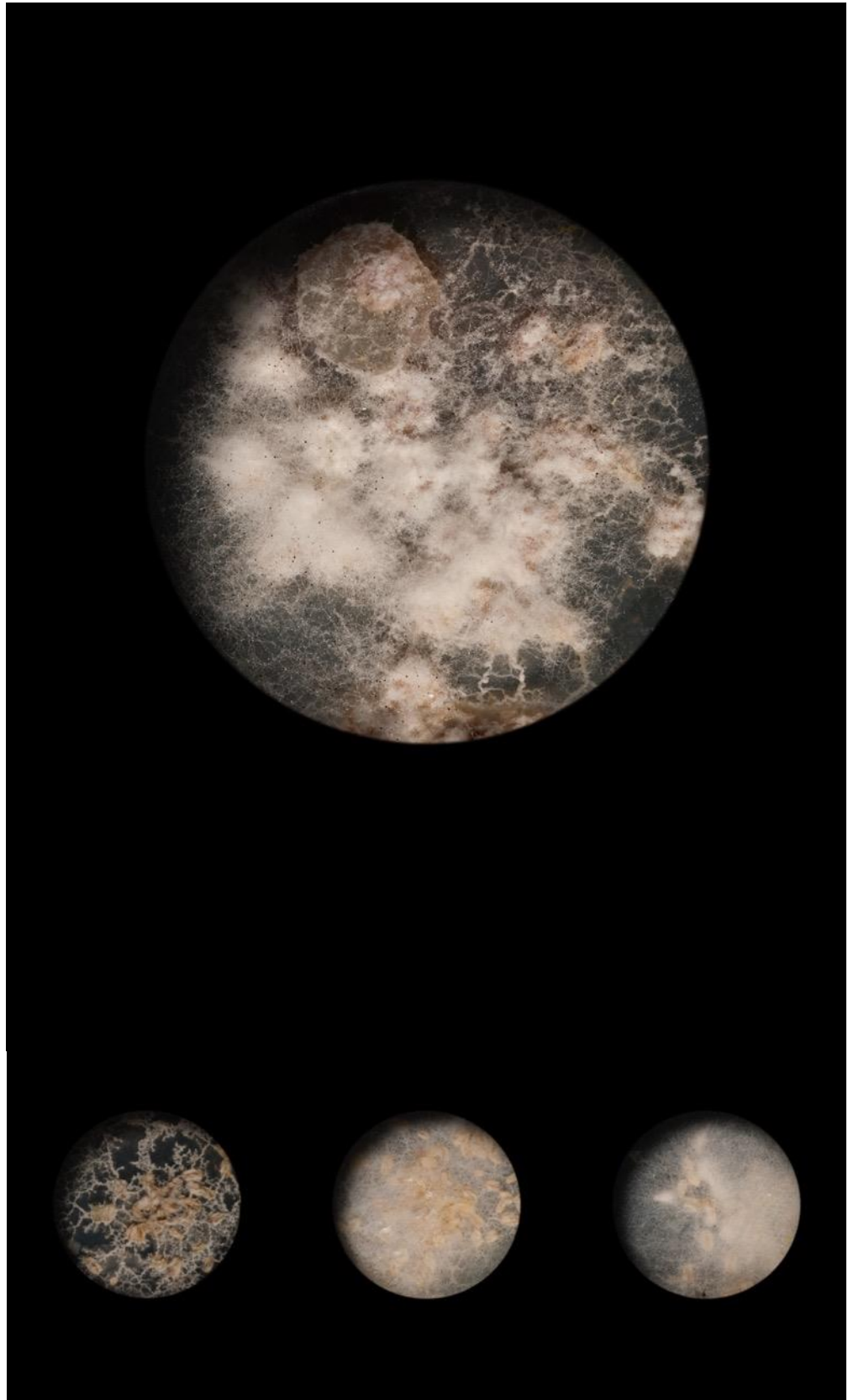


Fig 16: *Remnants of a Process* by Heather Barnett. The aftermath of the experimental process, as food moulds move in after the slime mould has exhausted resources. Archival digital photographic prints (45 x 55cm)



Fig 17: *Patterns of Behaviour* by Heather Barnett. Chalk drawings made by following the bifurcation rules evident in many natural systems, where growth iteratively branches out to maximise coverage and access to resources. Unique chalk drawings on paper: (90 x 70cm)

Staging the Organism | exhibiting *The Physarum Experiments*

Works from *The Physarum Experiments* have been exhibited internationally, including:

- *World Machine*, OÖ Landes-Kultur, Linz, Austria (2022)
- *Art in FLUX*, Victoria & Albert Museum, London (2019)
- *La Fabrique Du Vivant*, Pompidou Centre, Paris (2019)
- *Nonhuman Networks*, Art Laboratory Berlin (2017)
- *Anthropocene Island*, Tallinn Architecture Biennale, Estonian Museum of Architecture (2017)
- *Testing Station [Crowd Control]* – arebyte gallery, London (2017)
- *Menagerie of Microbes – Bio and Beyond*, Summerhall, Edinburgh (2016)
- *BioDesign: On the Cross-Pollination of Nature, Science and Creativity* – The New Institute, Rotterdam (2013)
- *Cut/Paste/Grow* – The Observatory, New York (2013)
- *The Physarum Experiments* – Margate Photo Fest (2012)

Biodesign: On the Cross-Pollination of Nature, Science and Creativity

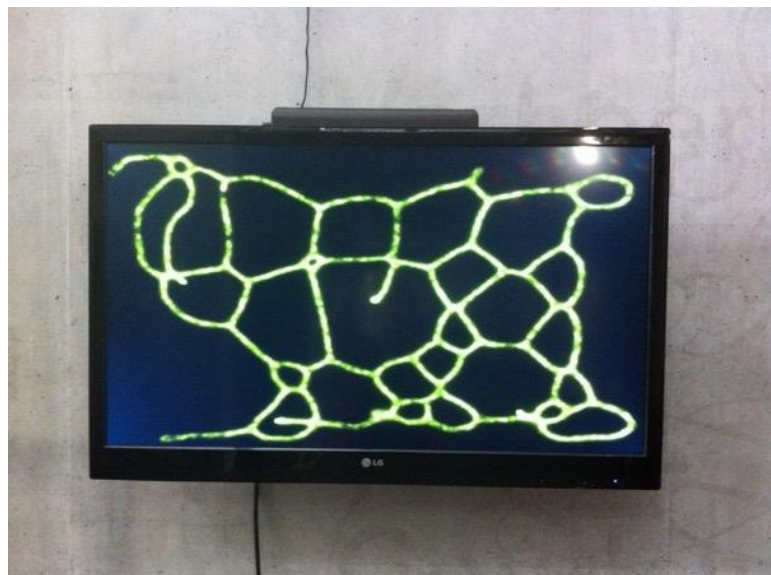
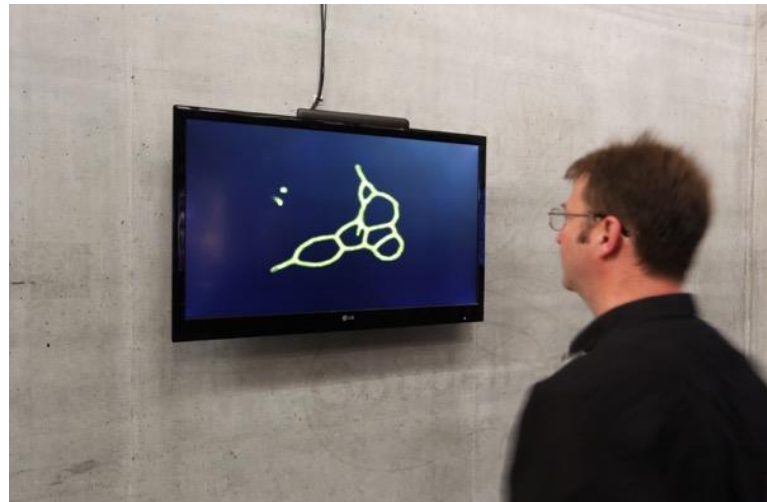


Fig 18: Gallery installation view of interactive piece, inviting viewers to become virtual food nodes for the digital slime mould simulation to network between, Biodesign, Neu Museum, Rotterdam.
Photos by Heather Barnett

Menagerie of Microbes

Laboratory Gallery, Summerhall, Edinburgh

25 March – 13 May 2016

Curated by Heather Barnett and James Howie (ASCUS Lab).



Fig 19a: Installation views of *Menagerie of Microbes*. Photo by Diego Almazán

Menagerie of Microbes celebrates the microbial world, bringing together the work of artists, designers and scientists who share a passion for microorganisms, which exist in and around us. Combining works from different disciplinary perspectives, the exhibition reveals different modes of creative inquiry – how we observe and interact with the natural world, and how we work with biological materials and systems in order to create, question or communicate.

Menagerie of Microbes presents work by Heather Barnett, Anna Dumitriu, ecoLogicStudio, Patrick Hickey, Simon Park, Sarah Roberts, Urban Morphogenesis Lab and the ASCUS Lab, and is part of Bio and Beyond, the visual art exhibition at Summerhall for the Edinburgh International Science Festival 2016.

Exhibition film by Diego Almazán: <https://youtu.be/c5o75MAwapo>

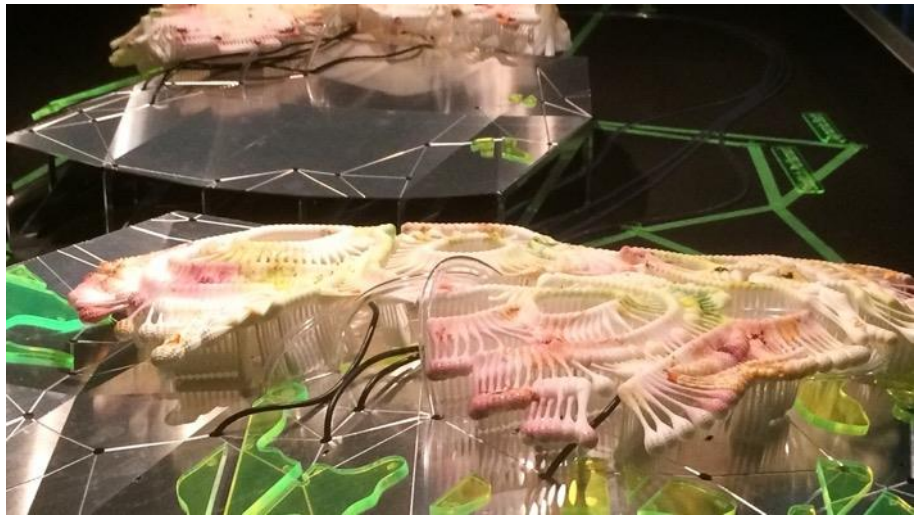


Fig 19b: Installation views of *Menagerie of Microbes* (from top): topography of Arthur's Seat powerstation concept design by ecoLogicStudio; projection installation of *The Physarum Experiments* by heather Barnett; living moss and slime mould inhabit miniature terraria by Patrick Hickey. Photo by Diego Almazán

Nonhuman Networks

Art Laboratory Berlin

30 September – 26 November 2017

Curated by Regine Rapp and Christian de Lutz

In 2017 I was invited by Art Laboratory Berlin to contribute to the exhibition *Nonhuman Agents*, alongside Saša Spačal, Mirjan Švagelj & Anil Podgornik, who presented *MyConnect*, a cybernetic capsule merging human and mycelial communications in a mediated biofeedback loop. Within the exhibition I presented a selection of works from *The Physarum Experiments*, reflecting the diverse methods and media employed. Works included time-lapse studies, documentary and artistic films, a living sculpture and a digital artwork.



Fig 20: Installation view of *The Physarum Experiments* as part of *Nonhuman Agents*, Art Laboratory Berlin. The time-lapse studies and films are projected large onto the wall, accompanied by the film of *Swarm | Cell | City*, the collective experiment ran locally prior to the exhibition. Photo by Tim Deussen.



Fig 21: Installation views of *Nonhuman Agents*, Art Laboratory Berlin (from top): *Swarm | Cell | City* film screened alongside *Biocartographies* living sculpture; *Motion Field* digital artwork; *Spatial Negotiations* film screened. Photos by Tim Deussen.

Living Sculptures

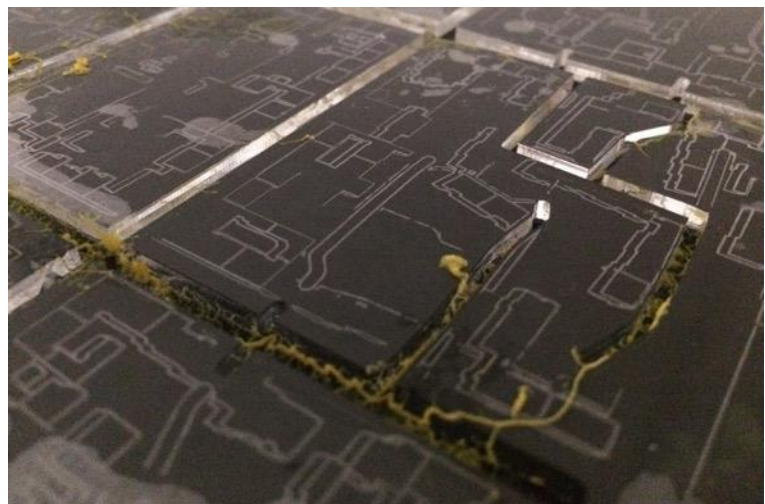
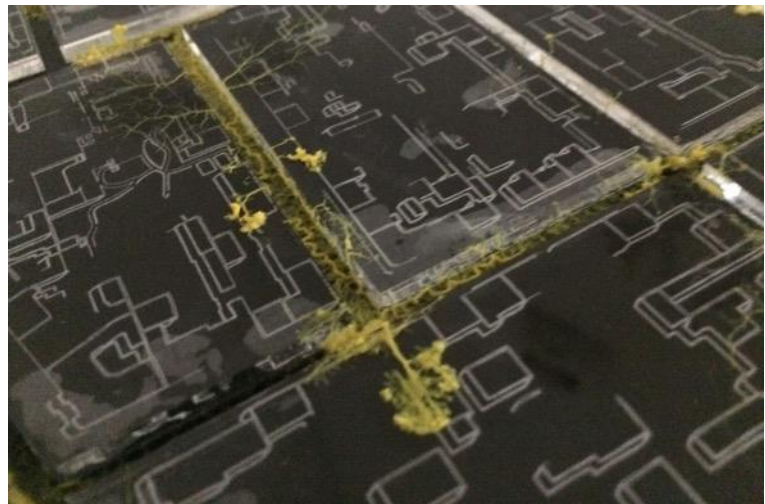
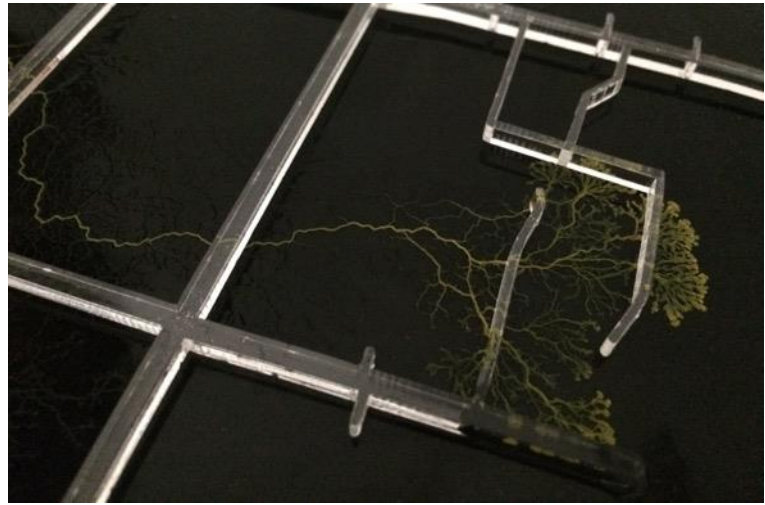


Fig 22: *BioCartographies* by Heather Barnett (live sculpture, 20 x 20 x 2cm, media: plastic, laser cut acrylic, agar, slime mould). *Nonhuman Networks* exhibition Art Laboratory Berlin, 2017. A laser cut map embedded into agar, depicting the area surrounding the gallery, with slime mould invited to explore its surroundings. The area offered to the slime mould cross-referenced the area explored by human participants during the *Swarm | Cell | City* collective experiment. Photos by Tim Deussen & Heather Barnett.

It offers the viewer an opportunity to experience the living organism in action though, at a top growth speed of about one centimetre per hour, this requires considerable patience and close nuanced observation. The frustration inherent within this act of viewing becomes part of the exercise, however, to give contrast between the spectacle of the slime mould writ large on-screen, its behaviour accelerated and amplified through time-lapse photography, and the real organism slowly creeping around the maze looking for nourishment. It is an attempt to bring the human viewer a little closer to the slime mould's temporal existence, to create a small perspective shift.

(Barnett, 2023 : 206)

B2: Systems of Co-enquiry



Fig 23: Introducing *Physarum polycephalum* to others at BOM, Birmingham (2015); human/slime mould petri dish experiments at GenSpace, Brooklyn (2013). Photos © Heather Barnett

My practice as an artist has co-evolved over the years with my practice as a teacher, each informing the other. Hence, workshops and educational activities have always played an important role in what I do as an artist. From science museums to floating cinemas, and from arts festivals to community laboratories, I have facilitated numerous workshops and participatory experiments bringing different groups of people into creative contact with the slime mould. The aim of these activities is threefold: for people to engage with the organism as a living subject to observe (an interesting specimen of non-neuronal intelligence – ‘isn’t it fascinating?’), an object of enquiry (a system of knowledge for research – ‘what questions are being asked of it?’) and, thirdly, a model for examining larger questions of communication and cooperation (a comparative model – ‘how do we relate to it?’).

(Barnett, 2019b : 27)

Workshops

Throughout the *The Physarum Experiments* I have conducted workshops in schools, museums, and galleries, universities in the UK (Royal College of Art, Bournemouth University, Central Saint Martins, University of Sussex) and the US (Harvard University, School of Visual Art, Hampshire College), community laboratories (GenSpace, New York; ASCUS Lab, Edinburgh; BioClub, Tokyo), festivals (Subtle Technologies Festival, Big Draw, Edinburgh International Science Festival), The Society of Biology and a floating cinema on a canal boat. Workshop formats adapt to suit different groups and contexts and the slime mould is framed to suit its new environment. However, the central remit remains consistent – to engage with the material epistemologies and nomadic concepts the slime mould presents.

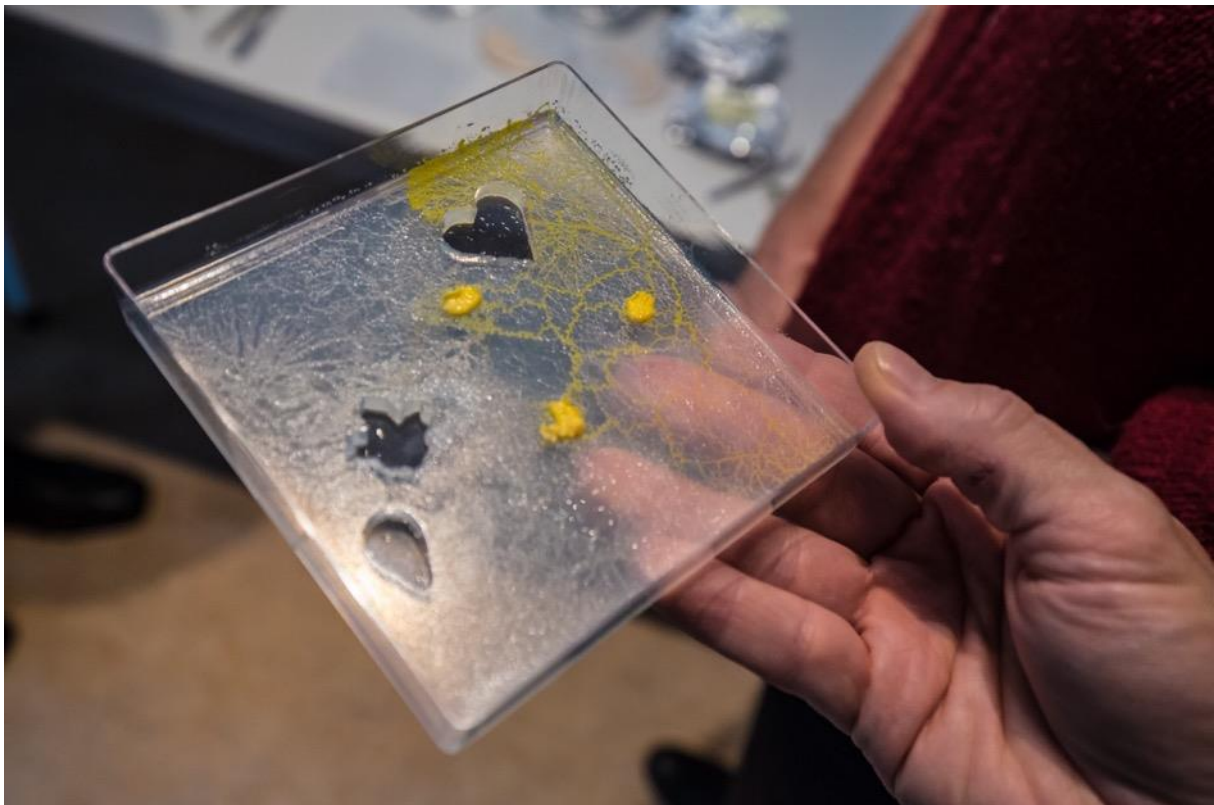


Fig 24: A plate of slime mould partially transplanted into participants experimental arenas, *Swarm | Cell | City*, Art Laboratory Berlin (2017).
Photo by Tim Deussen.

Workshops delivered between 2011-2019

2019

Crossing Kingdoms: Co-creating with Nonhuman Others, Shared Campus, Zurich
The Physarum Experiments, Artist and the Machine, Barbican Centre, London
City Superorganism, York University & University of Toronto, Canada

2018

Into the Mountain: A Meet, Tramway, Glasgow
Fluid Rhythms, Open Set, Amsterdam
Species Intelligence Conference, Harvard University, USA
Reimagining Munich, City as Superorganism, Munich
Playful Learning Conference, Manchester
Bioclub, Tokyo
Many-Headed, Hikari, Tokyo

2017

Crowd Control, collective behaviour experiments, arebyte gallery, London
Being Biological, Scratch Night, Coney and Theatre Delicatessen, London
Systems Games Nights, arebyte gallery, London

2016

Systems Games STEAM workshop, The Metropolitan Museum of Art, New York
Systems Games Night open workshop, Qlab, New York
The Physarum Experiments, ASCUS Lab, Summerhall, Edinburgh
Slime Mould Boot Camp, Central Saint Martins, London

2015

Designing with biological behaviours, Royal College of Art, London
The Physarum Experiments, BLAST, Bournemouth
The Physarum Experiments, BOM, Birmingham

2014

The Physarum Experiments, The Society for Biology, London

2013

The Physarum Experiments, University of Sussex, Brighton
The Physarum Experiments: GenSpace, New York

2012

The Physarum Experiments: Subtle Technologies Festival, Toronto

2011

The Physarum Experiments: University of the Arts, London
The Physarum Experiments: GenSpace, New York



Fig 25: *The Physarum Experiments*: GenSpace, New York (2011) (from top): preparing experimental petri dish plates in the lab; participants creating slime mould experiments and viewing the organism through the microscope; a petri dish experiment testing navigational abilities. Photos © Heather Barnett



Fig 26: Presenting *The Physarum Experiments* and running a practical workshop at Subtle Technologies Festival, Toronto (2012)
Photos © Heather Barnett.



Fig 27: Intergenerational workshop at The Society for Biology, London (2014). Bottom picture: a boy of 11 speculating on the possibility of genetically engineering the slime mould to become bioluminescent only for it to have a paradoxical crisis caused by its dislike for light. Photos © Heather Barnett



Fig 28: *The Physarum Experiments*, BLAST, University of Bournemouth (2015) (from top): aesthetic decisions regarding experimental design; alternative maze experiments; the joy of viewing protoplasmic streaming down the microscope. Photos © Heather Barnett

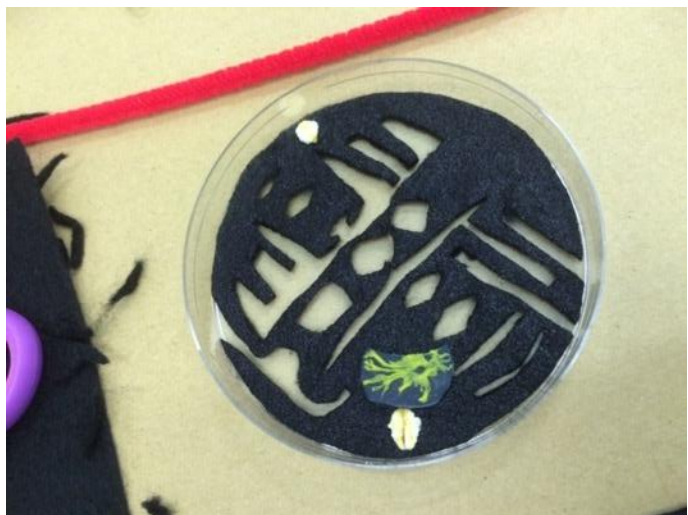
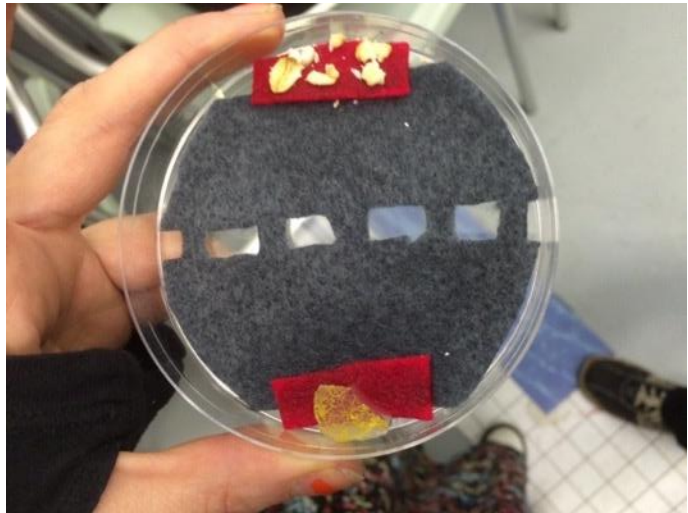


Fig 29: Designing with biological behaviours, guest lecture for MA Design Interaction at the Royal College of Art, London (2015).
Photos © Heather Barnett

Collective Experiments

Through the workshops it became evident that the slime mould was a valuable *discourse object* (Rheinberger, 1997), a living organism capable of carrying concepts, provoking philosophical questions, and embodying processual thinking. The myriad modes of attunement - each participant bringing their own curiosity and enquiry to meet the model organism - made it an exemplar *boundary object*, “a set of work arrangements that are at once material and processual” (Star, 2010 : 604), for exploring the structures and functions of network behaviours across social, technological, and biological systems. Whilst workshops allowed me to introduce the organism to others in material form and raise certain questions and possibilities in people’s minds, more complex frameworks for co-enquiry were needed to fully explore the potential of the organism as a vehicle for ontological and epistemological enquiry. I wanted to bring others into that enquiry, many heads exchanging and building knowledge in one shared ‘adisciplinary’ space, to gather diverse expertise around the organism and extend its reach to wider publics. I wanted to further create the conditions for open experimentation - to question through creative, critical, and exploratory practices - to see where the slime mould might take us.

Between 2015-2019 I conducted five collective experiments in different cities, invited by curators, scholars, artists, and collectives. Each experiment extended collaboration and grew the network of slime mould enthusiasts:

- 2015 Nodes and Networks (New York City)
- 2017 Swarm | Cell | City (Berlin)
- 2018 City Rhythms (Amsterdam)
- 2018 City as Superorganism (Reimagining Munich)
- 2019 City as Superorganism (Toronto)

Nodes and Networks (New York City)

In December 2015 I was invited to participate at the International “Physarum Transport Networks Workshop”, held at Columbia University, an interdisciplinary scientific meeting for researchers working with the network potential of *Physarum polycephalum*. The event organizer, Professor Hans-Günther Döbereiner, a biophysicist based at Bremen University, was interested in the wider applications of the organism, beyond purely scientific contexts, and invited me to present my work alongside other arts and educational researchers. Keen to extend the encounter between artistic and scientific slime mould enquiry beyond the walls of Columbia University and out into the city, I developed a public facing collaborative experiment, *Nodes and Networks*, inviting a team of artists, writers, architects, and designers, working with networked systems in the context of New York City, to work with visiting scientists from the fields of biophysics, ecology, genetics and neuroscience. The intention was to broaden the reach of the academic conference through interacting with local researchers and practitioners working from diverse disciplinary backgrounds, but with a common interest in biological networks and their related sociotechnological formations. A core group was recruited from my existing contacts, each person extending the invite to others they knew engaged with concepts and mechanisms of networks across systems and scales, thereby growing the community. Through this process, eighteen researcher-practitioners came together over two evenings to co-design an intensive day of interdisciplinary investigations open to the public.

The methodological framework followed two phases, initially bringing professionals working in ‘network’ orientated fields together to exchange concepts, frameworks, and reference points. Secondly, non-specialists from wide disciplinary fields were invited into that conversation through practical experimentation. The experimental playground included the School of Visual Arts’ BioArt Lab (who hosted the experiment), the Metropolitan Museums’ Media Lab, Central Park and the New York subway system. SciArt magazine published a multi-authored account of the collaboration, presenting perspectives from some of the collaborators (Barnett et al., 2016) (Portfolio Published Text 1).



Fig 30: A multidisciplinary team of ‘networkologists’ (artists, scientists, ecologists, designers, etc) generating ideas and co-developing network experiments for public participation for *Nodes and Networks* at the School of Visual Arts, New York. Photos by Jared Vaughan Davis and Heather Barnett.

The nature of the experiments varied. Material exploration in the laboratory used attractants and repellents as a means to create social maps of the New York boroughs, exploring subjects of pollution, crime or gentrification. Modelling experiments played out in Central Park, adapting the rules of Being Slime Mould to affect motivation, communication, and collective coordination. Finally, The Metropolitan Museum of Art provided a human petri dish for us to conduct a series of cultural foraging experiments tracking human behaviour in the galleries (whilst back in the lab the slime mould was exploring a scaled down 3D model of the same territory).

(Barnett, 2019b : 30)

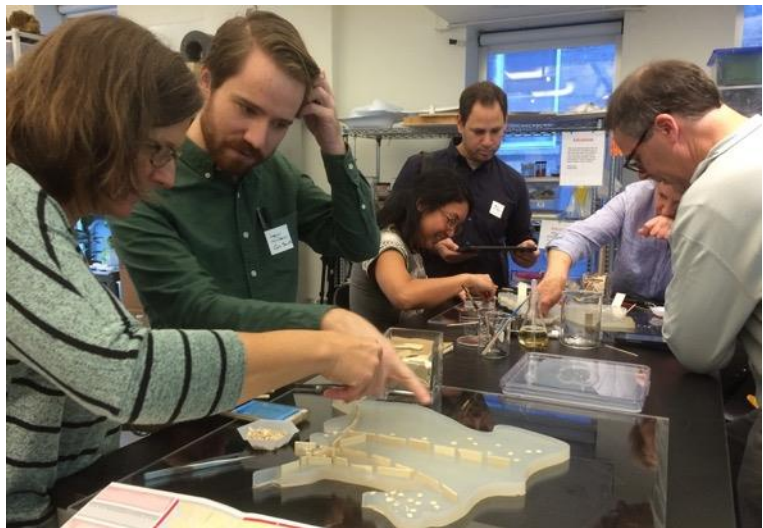


Fig 31: Participants creating topographic maps of New York City boroughs, enticing slime mould to model human environmental concerns such as, pollution, gentrification, or traffic control – responding to given attractants and repellents. *Node sand Networks*, School of Visual Arts Bioart Lab. Photos by Jared Vaughan Davis and Heather Barnett.

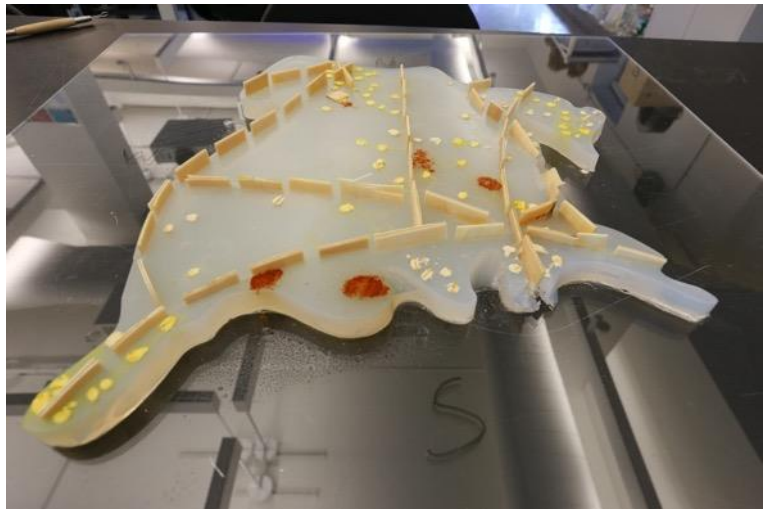


Fig 32: The results of the topographic modelling experiments after the slime mould had explored the New York boroughs and responded to given attractants and repellents in the environment. Barriers and points of connection are interpreted from humancentric positions and the speculated perspective of slime mould. Photos by Jared Vaughan Davis and Heather Barnett.



Fig 33: Participants navigating the terrain of the city and exploring collective behaviour mechanisms through a version of *Being Slime Mould*, the rules adapted by a biophysicist. Central Park, New York City. Photos by Jared Vaughan Davis and Heather Barnett.



Fig 34: Participants conducting a 'foraging and tracking' exercise in the galleries of the Museum of Modern Art, observing human behaviours in the act of cultural consumption. The experiment involved tracking visitors' movements and compiling field notes on behaviour. Photos by Jared Vaughan Davis and Heather Barnett.

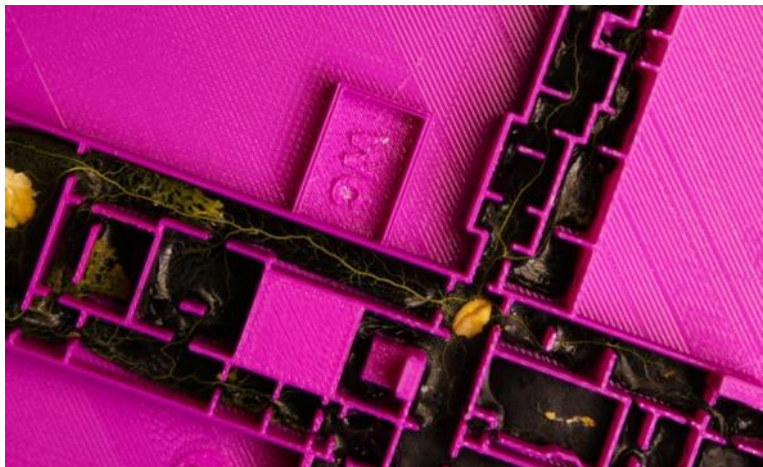


Fig 35: While participants were tracking gallery goers in the Museum of Modern Art the slime mould was back in the Bioart Lab at SVA navigating a scaled down 3D print of the same galleries in a relational foraging exercise. Photos by Jared Vaughan Davis and Heather Barnett.

Nodes and Networks provided an opportunity to combine different methods of research with participatory art practices, situated in a specific location and context. Through a partially self-organising process, everyone involved could explore different ways of thinking about networked intelligences and collectively contribute knowledge and experience. The project brought many heads together to create novel ideas through a creative emergent process.

(Barnett, 2019b : 30)

Swarm | Cell | City (Berlin)

In 2017 I was invited by Art Laboratory Berlin to contribute to the exhibition *Nonhuman Agents*. Building on *Nodes and Networks* in New York, I wanted to further develop the collaborative workshop-performance activity which articulated how slime mould could function as a modelling system and relational device to examine human systems (urban, social, technological, and cultural) and explore how people interact with and respond to their environment (individually and collectively). In order to connect with the gallery locality and context, and to bring other disciplinary areas into the enquiry, I sought to work with local researcher-practitioners to co-design a situated collective experiment. The curators of Art Laboratory Berlin, Regine Rapp and Christian de Lutz, suggested plan b (Sophia New & Daniel Belasco Rogers), a performance duo based in Berlin working with mapping, data visualization, and identity. Ideas developed for *Swarm | Cell | City*, merging our disciplinary methods and perspectives.

The intention was for the event to take place prior to the gallery opening so that a film documenting the activity could be included in the exhibition. We invited 12 local participants from diverse backgrounds and over two days conducted research activity utilising the area surrounding the gallery. This local *umwelt* was employed as an urban petri dish for a series of speculative exercises in which participants were invited to undertake situated experiments, shifting perspective from human to non-human collective lifeforms. The aim of these experiments and encounters – a hybrid form incorporating methods from material thinking, improvisation and performance - employed the slime mould as a material and conceptual model to broker insights into human behaviour, a *discourse object* that shifted perceptions of our ecological interrelations.

Over two days the collective experiment was filmed by Tim Deussen and the resulting documentary film was screened in the exhibition.

The film can be viewed here: <https://youtu.be/BZTpxQmRsCI>

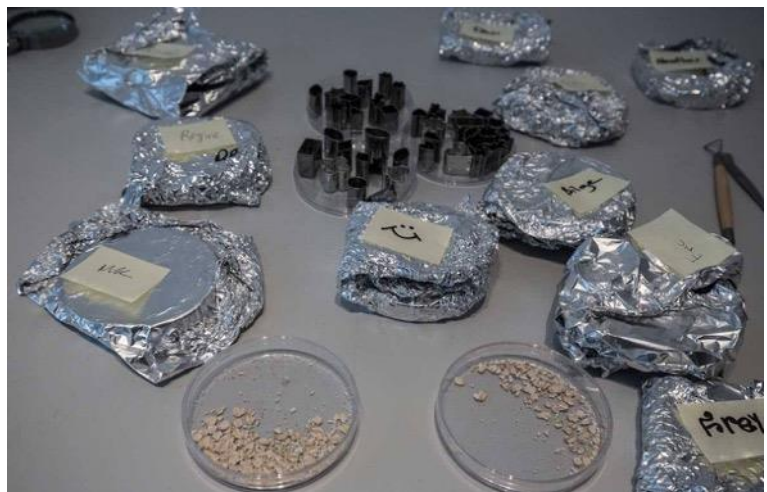
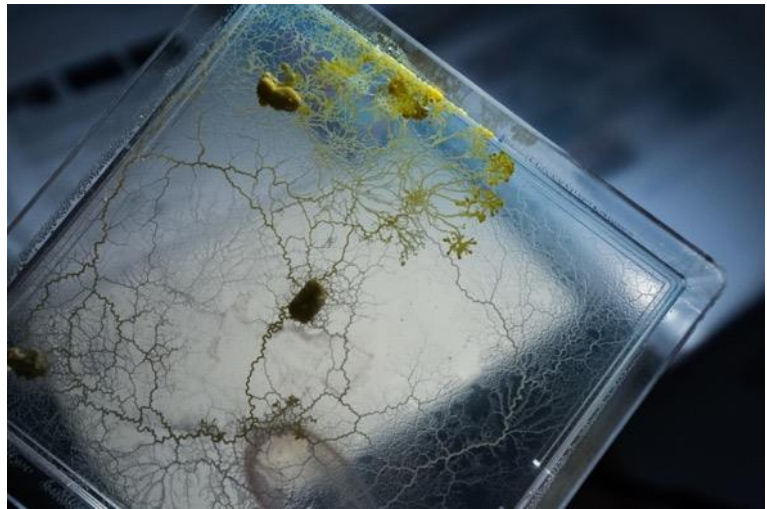


Fig 36: Individual material experiments: designing and building an environment in a petri dish to test the capabilities of slime mould. *Swarm | Cell | City*, Art Laboratory Berlin. Photos by Tim Deussen & Heather Barnett.

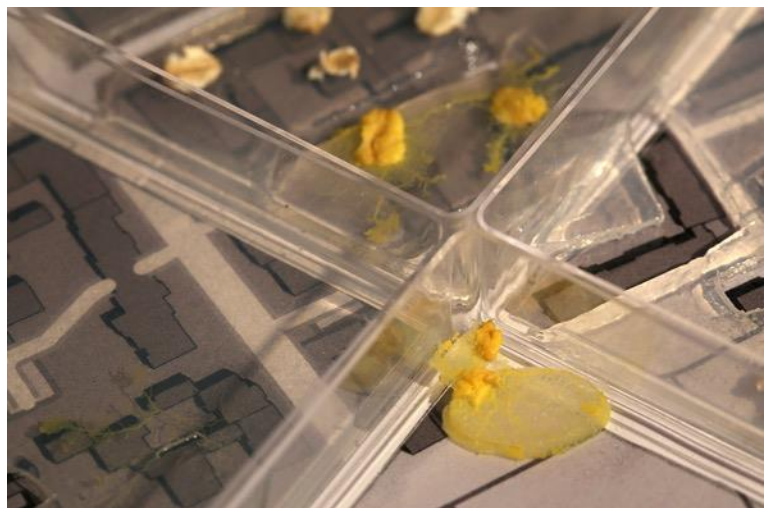
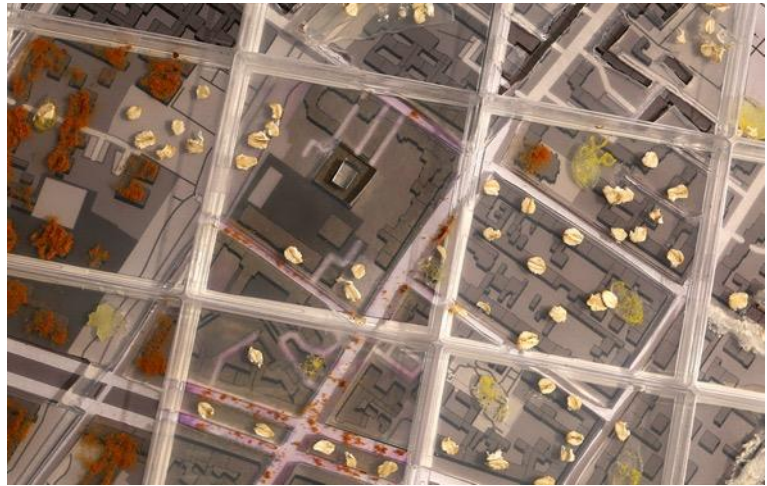


Fig 37: Collective mapping experiments: participants explored the environs around the gallery from an imagined other than human perspective and mapped their findings onto an agar map of the locality.
Photos by Tim Deussen & Heather Barnett.



Fig 38: Collective trace-making: devising systems for indirect communication by traces left in the environment, where temporary chalk markings create a symbolic language. Experiment inspired by biosemiotic stigmergic processes, whereby traces left in the environment transmit information to other organisms. Photos by Tim Deussen & Heather Barnett.



Fig 39: Collective navigation part A: a movement experiment following simple herding rules of proximity and distance which was GPS tracked to map the individual and collective movements of the group. This experiment employed a biological behavioural model of attraction and repulsion to set up a simple rule-based system to direct unspoken coordination and leaderless decision-making resulting in emergent navigational outcomes.

Photos by Tim Deussen & Heather Barnett.

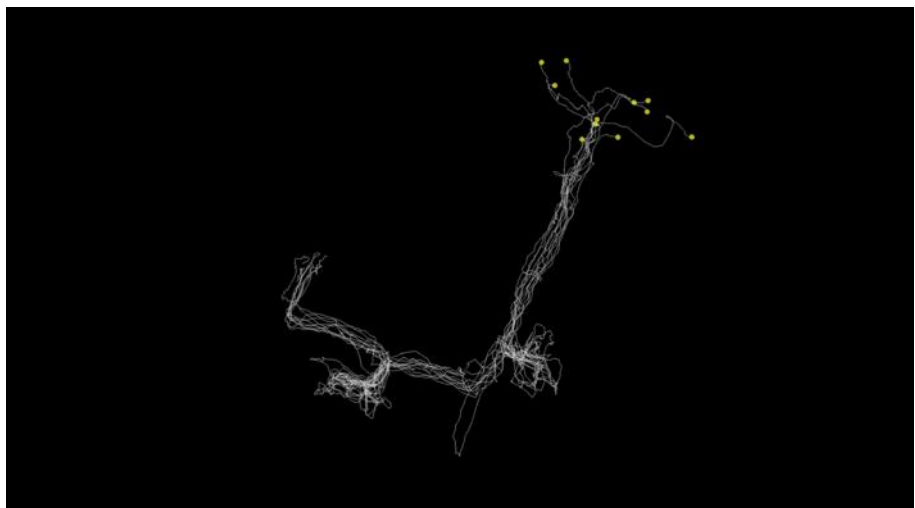
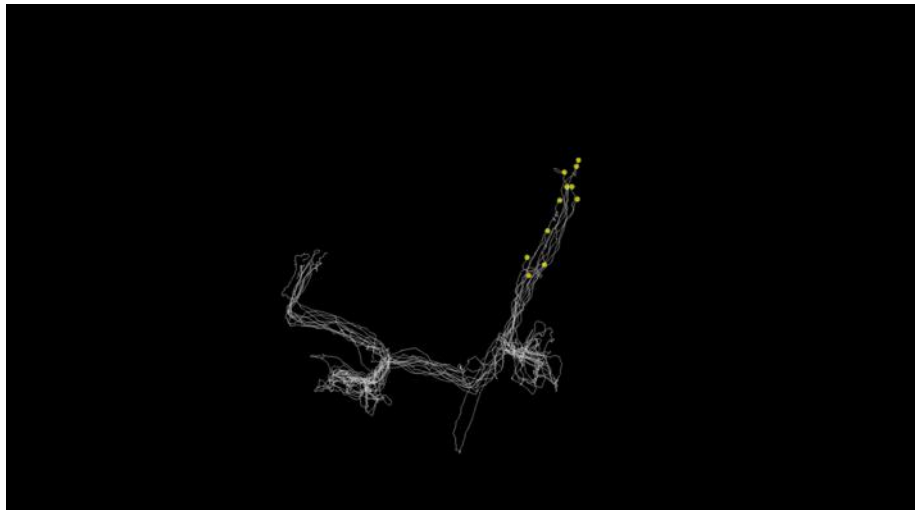
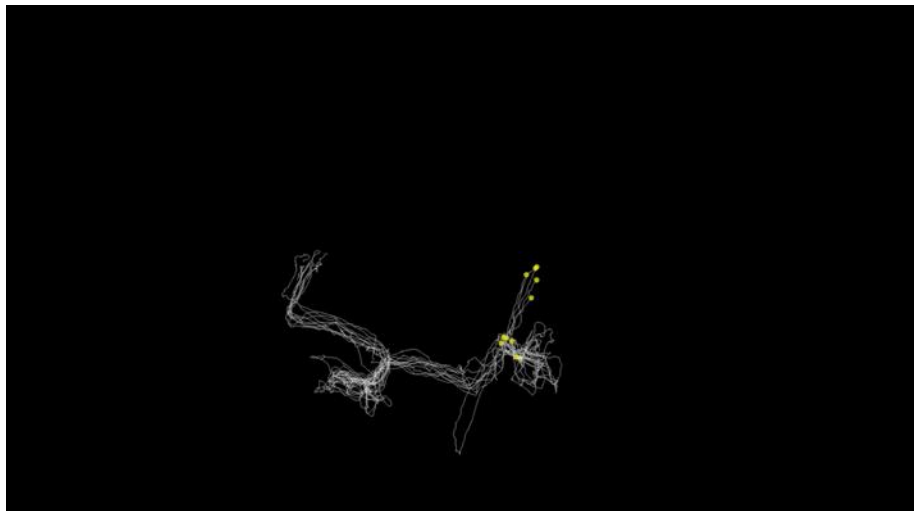


Fig 40: Collective navigation part B: Film stills of the resulting GPS tracking of individual and global movements of the group. A relational exercise shifting scale between the networking behaviour of a microorganism to planetary modes of surveillance, via human urban exploration. Images © plan b and Heather Barnett

Within the group I recall a biochemist, an anthropologist, a choreographer, several artists, and a writer - typical of most slime mould workshops, where disparate disciplinary backgrounds centre around the organism from individual points of interest. Questions raised during the two days were plentiful ... discussion ranged from curiosity about pigmentation and colour indicators, through questions of epigenetics and learned behaviours passing through generations of cell lines, to philosophical musings on a duty of care towards nonhuman organisms and recognition of the slime mould's performance (sacrifice) for our intellectual curiosity. Throughout the workshop, the slime mould operated as a springboard for sympoetic working – collectively exploring, experiencing and discovering.

(Barnett, 2019b : 31)

City Rhythms (Amsterdam)

In August 2018 I was invited to contribute to a Summer School organized by the Dutch independent design education platform, Open Set, on the theme of city rhythms. Set within the context of the Bijlmer, an urban area once envisioned as an architectural utopia and today one of the most vibrant neighborhoods in Amsterdam. Open Set promotes the social relevance of design and visual culture through a programme of labs, activities and networking opportunities, describing their ideology as “a new model for school, laboratory, and community hub” (*Open Set*, no date).



Fig 41: The Bijlmer estate in Southeast Amsterdam, Siegfried Nassuth's 1965 masterplan for urban renewal and environmental attunement.
Photo by Heather Barnett.

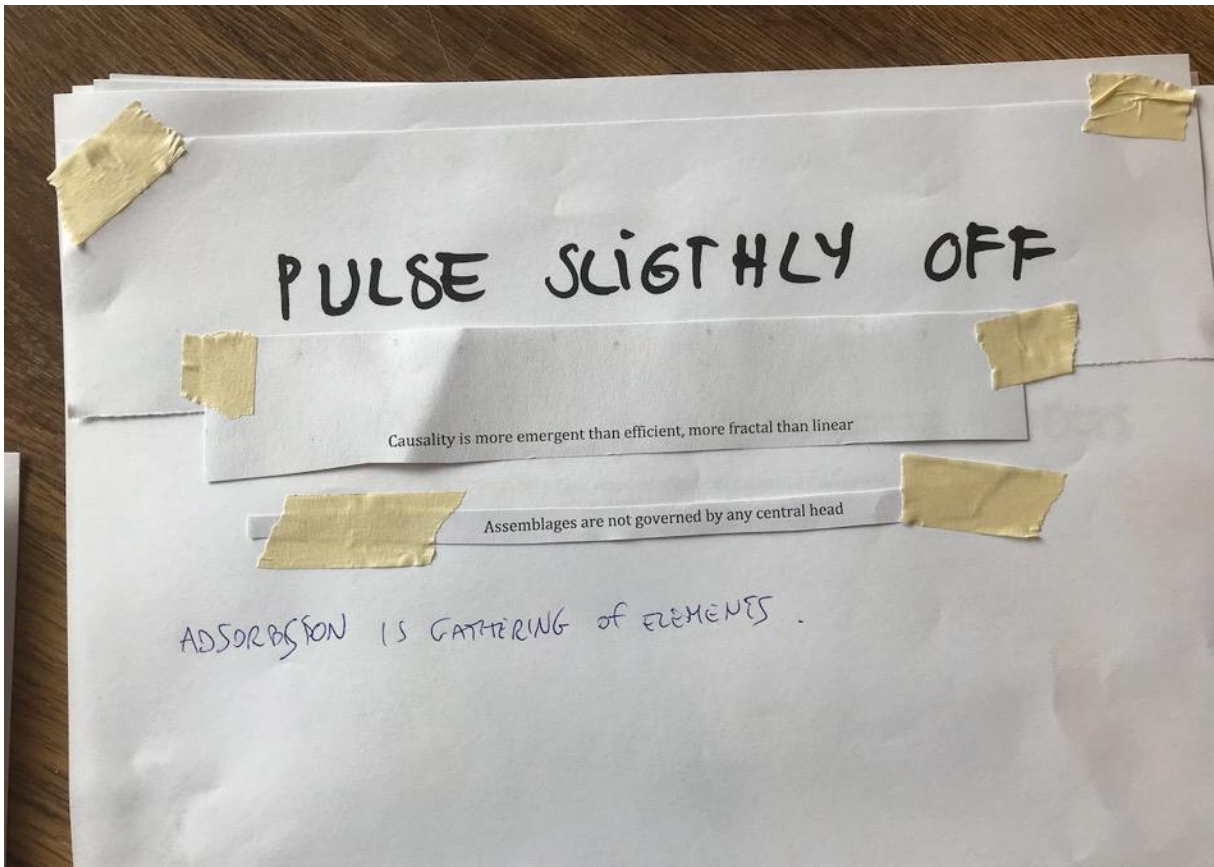
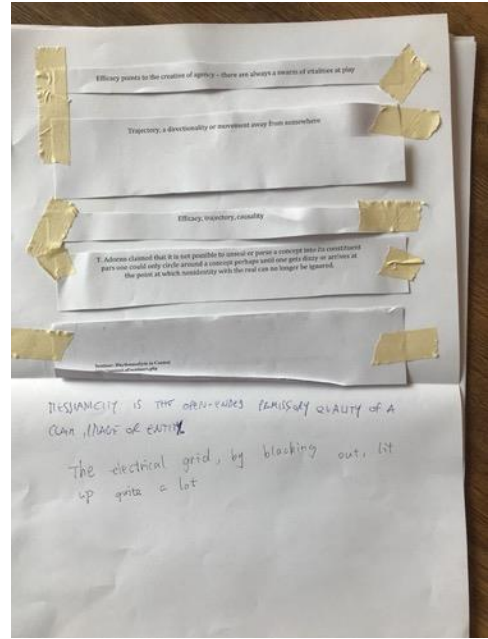
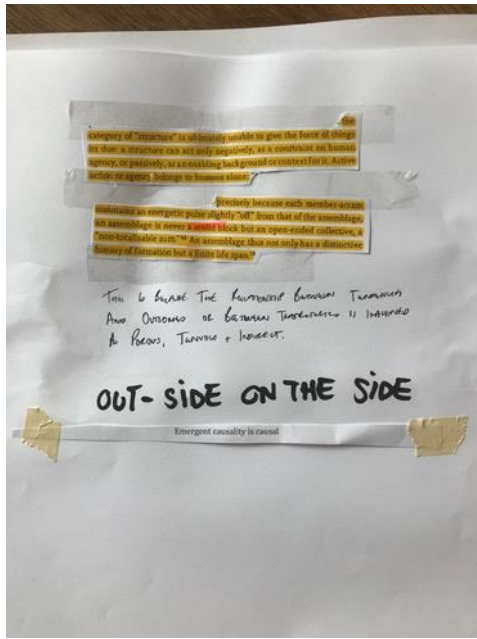


Fig 42: Collective concrete poetry created with excerpts from Jane Bennett's *Vibrant Matter* – selected sections included observations of discarded detritus and the invisible rhythms of urban infrastructure. Photos by Heather Barnett.



Fig 43: Mapping exercise layering in/visible informational rhythms of the city, examining the site of Bijlmer from a slime mould perspective, and mapping attractions/repellents in the environment. Photos by Heather Barnett.

City as Superorganism (Reimagining Munich)

In September 2018 I was invited to run a two day workshop by the “Arbeitskreis (Ak) Zur Resozialisierung von Gemeinem Grün” / "Working Group for the Resocialization of Common Green", a group of artists and scientists raising awareness of the reciprocal nature of city living through a form of “promenadology (the science of strolling) by way of ground research to help us with the topics of nature/wildness, culture, order, and chaos.”. As part of their series *City Streaks*, I devised a series of city-wide experiments to “examine social, ecological, political, and aesthetic aspects, with the aim of sharpening our perception of the environment, and to expand and gain a deeper insight into the structures of our city lives.” (‘Stadtdurchstreichungen 2018’, 2018).



Fig 44: Interspecies Psychogeography: re-imagining the city from the sensory subjective position of the slime mould, building a collective map modelling perceived preferential habitats and routes through the city. Photo by Jutta Czeguhn.



Fig 45: Interspecies Psychogeography: re-examining the city from the sensory subjective position of the slime mould, identifying preferred habitats. Photos by Jutta Czeguhn.

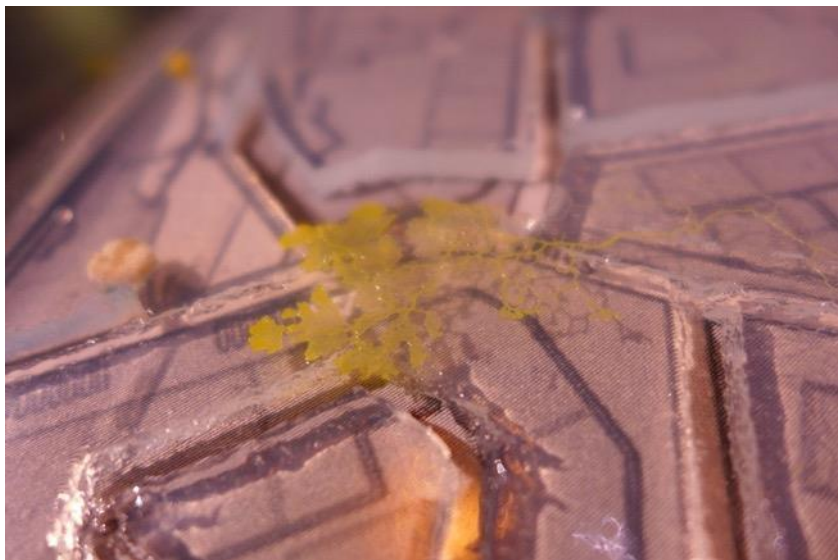


Fig 46: Interspecies Psychogeography: re-imagining the city from the sensory subjective position of the slime mould, translating perceived preferences onto a moist map for slime mould exploration. Photos by Jutta Czeguhn.



Fig 47: Stigmergic traces: creating semiotic interventions, interrupting the flow of pedestrian traffic in the city. Photos by Jutta Czeguhn.



Fig 48: Stigmergic traces: creating semiotic interventions in the city, testing the attentiveness of changing environmental factors.
Photos by Jutta Czeguhn.

The workshop was attended by around twenty people (representing the usual diversity of expertise, including artists, ecologists, and teachers) and followed by a local journalist, Jutta Czeguhn, who published an article in *Süddeutsche Zeitung* (Zeitung, 2018). The article reported on the different experiments, as participants became more deeply attuned to slime mould sensibilities, culminating in “the most difficult exercise: the group itself becoming a single, large heap of cells moving through the Maximiliansforum, with eyes closed, without using hands or language, without egos or hierarchies.” (ibid). This finale of *Being Slime Mould* shifted the rules of slime mould communication across to a human collective superorganism. “For the participants, the temporary existence as a slime mold was an amazing experience that raised questions about communication and cooperation, about the collective and the individual in the super-organism city. For a man who happened to be passing the underpass, the sight of the giggling, chaotic mob was obviously a perfectly normal urban phenomenon; he took a photo and went on his way unperturbed” (ibid).




Fig 49: *Being Slime Mould* in the city underpass of the Maximiliansforum in Munich, a collective sensory exploration of the *umwelt* (surrounding world). City as Superorganism, Reimagining Munich. Photo by Heather Barnett.

City as Superorganism (Toronto)

In March 2019 I was invited by artist and academic, Robert Buiani, to contribute to an experimental course for the University of Toronto's Institute for the History and Philosophy of Science and Technology. The experiment in interdisciplinary pedagogy explored the interrelationships of society and digital technology with the city of Toronto as a site for exploration. Challenging the dominant vision of cities as information ridden computational machines, the course examined the complex multilayered messiness of the city, taking Toronto as a live case study. Over several weeks, students from across a range of courses (including physical science, social science and humanities subjects) were asked to question definitions of what makes a city 'smart' and to investigate the complexity of interconnected networks "as a multilayered conglomerate of architecture and urban planning, humans and animals, plants and technological infrastructures, biology and information" (Buiani, 2020 : 34). The pedagogic experiment is mapped out in this paper in the Journal of Science and Technology of the Arts:

Journal of Science and Technology of the Arts
Vol. 12, No. 1 (2020) - Special Issue: Consciousness Reformed

We have always done it wrong: the city as complex network, superorganism and more-than-human sentient being. An experiment in interdisciplinary [re]thinking.

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ABSTRACT

This paper draws on an experiment in interdisciplinary pedagogy, which took place in the Winter 2019, during a course on "Digital Technology and Society" at the University of Toronto. During the course, the city was chosen as the main source of inquiry. At the core of this experiment was a concern that current models of the city as "Smart City" have become disproportionately skewed towards the implementation of digital technologies, creating monocultural conceptions that prioritize predominantly anthropocentric top-down visions, and neglect the rich more-than-human layers of networks and naturecultural relationships shaping the city today. This concern has been addressed by a number of scholars such as Shannon Mattern (2016, 2017), James Bridle (2018) and Erik Swyngedouw (2006), while alternative views by new materialists such as Jane Bennett (2009), and human geographers Sarah Whatmore (2005) and Ruth Panelli (2010) among others have better addressed the complexities and the multispecies intersections, unfolding within urban conglomerates, and making up the urban technocultural fabric. Students were asked to reflect on the following questions: What is a Smart City? How is the city made smart [1]? Who/what makes it so? Is the city a complex system? Preliminary responses to the above questions reflected an exclusive vision oriented towards technological innovation. Introducing a fluid approach based on evidence from direct observation and in vivo exploration, hands on experiments with non-human others, and crossdisciplinary readings, challenged this perspective and nourished a different view of the city as a much richer, complicated and unpredictable entity where biology and information exist in symbiosis.

KEYWORDS
complexity, networks, computing, biology, superorganism, slime mould, Smart City

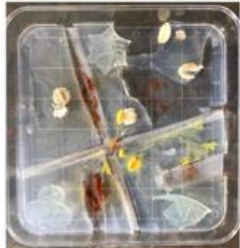


Image 1 | A shot from the first workshop on "Superorganism City" with Heather Barnett and Physarum Polycephalum Image courtesy of Maria Letizia Filippi

1 | INTRODUCTION

In December 2018 I received permission from New College (University of Toronto) to design an interdisciplinary course with an experimental mission: offered under the typically generic title "Digital Technologies and Society," the course gathered students from a range of disciplines in Social Sciences and Humanities, Computer Science, Physics and Mathematics. Although the course featured "digital technologies" in the title, I had much broader ambitions. In fact, limiting technologies to the digital, especially in a university context, discourages students from venturing beyond their routine role as users of apps, websites, games, etc.

My goal was to shake them out of their comfortable assumptions, to force them to review their conceptions of digital technologies and to challenge the assumed prominent role of the digital in society.

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<https://doi.org/10.34632/jsta.2020.8196>

Being Slime Mould

Being Slime Mould is a playful invitation to attune to slime mould sensibilities, to think through embodied experience and to reflect on that experience. The point of the exercise is in the attempt to dispense with the ontological burden of humanness for a short while and to embrace a shift into otherness. ... The 'rules' given relate to the morphological states, information distribution mechanisms and sensory communication strategies of the organism. The group is instructed to operate as a single mass entity, always in physical contact, though dynamic and able to constantly reshape. Communication is permitted only through oscillations; therefore verbal communication is forbidden and a physical means of distributing information must be improvised.

(Barnett 2019a : 164)

Being Slime Mould is a participatory experiment exploring slime mould ontologies. It is adapted to suit different contexts based on decoding and enacting behavioural rules.

These are the experiments to date:

2019

Crossing Kingdoms: Co-creating with Nonhuman Others, Shared Campus, Zurich

Being Slime Mould, 21st Century Common Sense, NESTA, London

The Physarum Experiments, Artist and the Machine, Barbican Centre, London

City Superorganism, York University & University of Toronto, Canada

Being Other Than We Are... Multispecies Storytelling Conference, Vaxjo, Sweden

2018

Into the Mountain: A Meet, Tramway, Glasgow

Fluid Rhythms, Open Set, Amsterdam

Reimagining Munich, City as Superorganism, Munich

Playful Learning Conference, Manchester

2017

Nonhuman Agents Conference, Art Laboratory Berlin

Crowd Control, collective behaviour experiments, arebyte gallery, London

Experiments in Elasticity, keynote speaker for ELIA Conference, Central Saint Martins

Being Biological, Scratch Night, Coney and Theatre Delicatessen

Systems Games Nights, arebyte gallery, London

Biodesign Challenge, Central Saint Martins, London

2016

Systems Games STEAM workshop for educators (via roaming robot), The Metropolitan Museum of Art, New York

Systems Games Night open workshop, Qlab, New York

Social Evolution Field Course, Rockefeller University, New York State

Collective Motion Conference, Uppsala, Sweden

Slime Mould Boot Camp, Central Saint Martins, London

2015

The Conference, Malmö, Sweden

The Lab Project Symposium, London

Open Embodiments Conference, Tucson, Arizona

Flatpack Film Festival, BOM, Birmingham

2014

FT Innovate Conference, London

2013

BioDesign I, New Institute, Rotterdam



Fig 50: The inaugural *Being Slime Mould* at BioDesign, New Institute, Rotterdam (2013).
Photos by Tim Grabham and Heather Barnett.



Fig 51: *Being Slime Mould* at The Conference, Malmö, Sweden (2015) with a delegation of 300 people. Photos by Heather Barnett and Richard Baxell.



Fig 52: An intimate *Being Slime Mould* at Open Embodiments Conference, Tucson, Arizona (2015).
Photos by Richard Baxell.



Fig 53: *Being Slime Mould* at Systems Games STEAM workshop for educators (beamed via roaming robot), The Metropolitan Museum of Art, New York (2016).
Photos by MET Media Lab.



Fig 54: Inviting collective behaviour scientists to participate in *Being Slime Mould* at the Collective Motion Conference, Uppsala, Sweden (2016).
Photos by Heather Barnett.



Fig 55: Slime mould as a metaphorical model for thinking about the educational ecosystem. *Being Slime Mould* at Experiments in Elasticity, keynote speaker for ELIA Conference, Central Saint Martins, London (2017).
Photos by Heather Barnett.

Being (or becoming) slime mould is of course an impossibility; we can no more become slime mould than we can become badger or bat. The point of the experiment, therefore, is in the trying: the attempt to put aside human ego and individualism for a moment in order to shift perception towards other ways of seeing, feeling and being. The slime mould - alien, yet relatable in so many ways - offers us a multitude of layers through which we can view ourselves and others simultaneously. To attune (in thoughts and actions) to an array of companion species, allows us to recognize the vast flow of diverse sensing, signaling, perceiving and responding that intercuts our interconnected worlds.

(Barnett, 2019a : 168)

Spatial Negotiations



Fig 56: Site for movement exploration in *Spatial Negotiations*, the Södra Bulltoftavägen, a former railway factory in Malmö, Sweden. Photo by Heather Barnett.

Spatial Negotiations is a sensory exploration of Södra Bulltoftavägen, a former railway factory in Malmö, Sweden. Inspired by the collective behaviour and spatial awareness of the slime mould, *Physarum polycephalum*, a group of dancers were invited to explore the historic urban architectural site. *Spatial Negotiations* is a collaboration with Swedish choreographer Emma Ribbing, working with filmmaker, Alexis Rodríguez Cancino, sound designer Silas Bieri and dancers: Christine Brorsson, Jilda J Hallin, Selma Kjesen, Rebecka Ohlsson, Celine Orman, Rumiko Otsuka, Malin Skoglund.

The resulting film derives from this piece of movement research, experiencing the materiality and atmosphere of space whilst operating as a nonhuman collective body: <https://www.youtube.com/watch?v=HYhZRjQ3B0w>. A second documentary film tells the story behind *Spatial Negotiations* - a sensorial exploration of urban development: <https://vimeo.com/325904368>



Fig 57: Development of *Spatial Negotiations* (from top): Heather Barnett and Emma Ribbing briefing dancers on the embodied cognition of slime mould; improvising a collective body; filming extended improvisations on location at Södra Bulltoftavägen. Photos by Alexis Rodríguez Cancino and Heather Barnett.



Fig 58: Film stills from *Spatial Negotiations*, collective movement exploration of a regenerated industrial landscape, Södra Bulltoftavägen, Malmö, Sweden. Filmed by Alexis Rodríguez Cancino.

Propagation of *polycephalism*

Public engagement and dissemination

The propagation of *polycephalism* (many headedness) has been central throughout the process of research, through invited lectures, online networking, and media appearances. As self-appointed spokesperson for slime mould subjecthood, I have disseminated research in a range of settings including academic conferences (across diverse disciplines), a TED Salon (Barnett, no date a), festivals (science and art), galleries and cultural events, and educational contexts.



Fig 59: Heather Barnett speaking at *Nonhuman Agents in Art, Culture and Theory* conference, Art Laboratory Berlin, November 2017. Photo by Art Laboratory Berlin.

Selected public engagement activity 2011-2019:

2019

Crossing Kingdoms: Co-creating with Nonhuman Others, Shared Campus, Zurich

Being Slime Mould, 21st Century Common Sense, NESTA, London

The Physarum Experiments, Artist and the Machine, Barbican Centre, London

City Superorganism, York University & University of Toronto, Canada

Being Other Than We Are... Multispecies Storytelling Conference, Vaxjo, Sweden

2018

Into the Mountain: A Meet, Tramway, Glasgow

Fluid Rhythms, Open Set, Amsterdam

Species Intelligence Conference, Harvard University

Reimagining Munich, City as Superorganism, Munich

Playful Learning Conference, Manchester

Bioclub, Tokyo

Interspecies Encounters, invited speaker PhysNet Conference, Bremen University
2017

Nonhuman Agents Conference, Art Laboratory Berlin

Crowd Control, collective behaviour experiments, arebyte gallery, London

Experiments in Elasticity, keynote speaker for ELIA Conference, Central Saint Martins

Being Biological, Scratch Night, Coney and Theatre Delicatessen

The Physarum Experiments, invited speaker at The Experiment Symposium, Tokyo
(CSM/TokyoTech)

Systems Games Nights, arebyte gallery, London

2016

Systems Games STEAM workshop for educators (via roaming robot), The Metropolitan
Museum of Art, New York

Systems Games Night open workshop, Qlab, New York

Being Slime Mould, Social Evolution Field Course, Rockefeller University, New York State

The Physarum Experiments, Collective Motion Conference, Uppsala, Sweden

Working with the microbial collective, BioChanges, Royal College of Art, London

The Physarum Experiments, ASCUS Lab, Summerhall, Edinburgh

Slime Mould Boot Camp, Central Saint Martins, London

2015

Designing with biological behaviours, Royal College of Art, London

Material Mechanical, Science Museum, London

Being Slime Mould, Lab Project, London

Biology and Art: learning from nature, The Conference, Malmö

The Physarum Experiments, BLAST, Bournemouth

Being Slime Mould, Open Embodiments conference, Tucson, Arizona

The Physarum Experiments, BOM, Birmingham

2014

Collective Intelligence, FT Innovate, London

Towards a Third Culture?, Overgaden, Copenhagen

The Physarum Experiments, TED Salon, Berlin

The Physarum Experiments, The Society for Biology, London

2012

The Physarum Experiments: Subtle Technologies Festival, Toronto

2011

The Physarum Experiments: University of the Arts, London

The Physarum Experiments: GenSpace, New York

The Slime Mould Collective

The Slime Mould Collective
An international network of/for intelligent organisms

Main Invite My Page Members Photos Videos Forum Links Events Groups Blogs Leaderboards Chat My Network

SLIMOCO brings together artists, scientists and others interested in slime moulds - to share research, knowledge, experiments, images...

Welcome to the Slime Mould Collective!
The Slime Mould Collective is a portal for interesting, progressive and ground breaking research and creative practice working with the simple yet intelligent organisms. If you are involved with or interested in slime moulds as a scientist, artist, designer, teacher, philosopher... (etc), please join and share what you do...
Also at www.facebook.com/groups/slimoco/

Forum

- Image request: Slime Mold Escaping!**
Started by Katie Losey in Links & Resources yesterday.
0 0
- Slime manifesto 6th edition fancy a proof read?**
Started by ian in Links & Resources. Last reply by RyChu Apr 22.
12 3
- How to get a physarum culture**
Started by ian in Links & Resources. Last reply by Katie Apr 20.
110 26
- Getting Plasmodia to sporulate and form sclerotia**
Started by Maxwell in Links & Resources Apr 19.
0 0
- Slime Mould Vibrations**
Started by Jana in Links & Resources Apr 11.
0 1
- Help! Why wont my slimes wake up?**
Started by Sarah Gracen in Links & Resources Mar 28.
0 0
- Interview on creative slime mould work**
Started by Zak Lakota-Baldwin in Projects & Ideas Mar 16.
0 0
- EPQ research**
Started by Thomas in Links & Resources Mar 13.
0 0
- Help? Slime mold to model effective transport routes in American School Districts**
Started by Evelyn Linford in Links & Resources Feb 28.
0 0
- Slime mould not going the distance**
Started by Danny in Links & Resources. Last reply by Sarah Roberts Feb 27.
1 0

Photos

Latest Activity

- Share: Blog Post · Discussion · Event · Video
- What brings you here?
- Maxwell posted a photo
Hemitrichia plasmodium 4-24-23
13 hours ago
0 Comments 0 Likes
- Jiasheng Chen commented on Jiasheng Chen's photo
S-Box
"Please credit Forenext Design Studio because it was one of our studio projects. Thank you!"
20 hours ago
- Katie Losey liked ian's photo
Progeny

Members

Groups

- Slimoco Paris**
7 members
3 1
- Dorset Slime Moulds**
1 member
0 0
- slimoco London**
15 members
8 1
- MatSliz**
2 members
2 2
- Hampshire/Harvard Worksh...**
4 members
0 2

Fig 60: Screenshot of slimoco (The Slime Mould Collective), the online network established in 2009 connecting slime mould researchers and practitioners across disciplinary divides and across continents. Membership totalling over 1700 includes artists, designers, scientists, ecologists, biology students and philosophers.

The Creeping Garden

The Physarum Experiments were extensively featured in the award-winning feature-length documentary film *The Creeping Garden* (2014), “a real life science fiction movie exploring a world creeping right beneath our feet” (*The Creeping Garden*, 2014). Over two years I worked with film-makers Jasper Sharp and Tim Grabham, permitting them to observe key moments of experimentation in the studio, time spent foraging for slime mould in the woods, and capturing the first attempt to entice people to ‘become’ slime mould. Other contributors include unconventional computer scientist, Andrew Adamatzky, mycologist, Mark Pragnall, bioacoustics musician, Eduardo Miranda, historian of science, Tim Boon, curator of mycology, Bryn Dentinger and roboticist, Klaus-Peter Zauner – the film presenting a rhizomatic narrative of intertwined investigations into plasmodial slime moulds.



Fig 61: DVD of *The Creeping Garden* feature length documentary film which features *The Physarum Experiments* by Heather Barnett, and accompanying publication which has also been translated into Japanese.
Photo by Heather Barnett

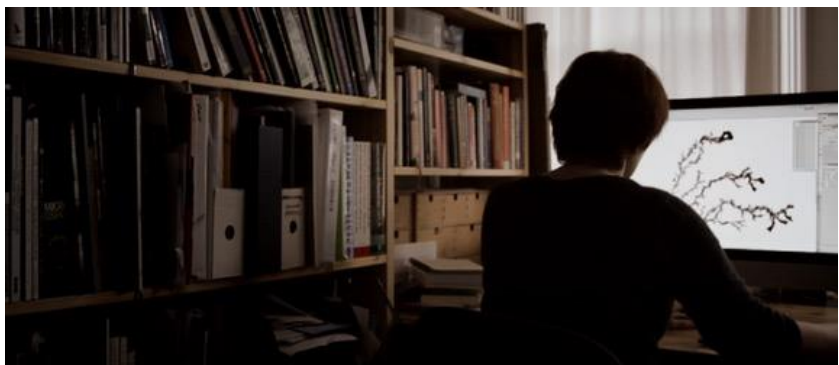


Fig 62: Film stills from *The Creeping Garden*, the feature length documentary film which features *The Physarum Experiments* by Heather Barnett, directed by Jasper Sharp and Tim Grabham (2014).
Images © The Creeping Garden

B3: Published Texts

The following invited texts have been published within peer reviewed journals, academic anthologies and editorial magazines:

1. Barnett, H. et al. (2016) 'Nodes and Networks: New York City', *SciArt Magazine*, August, pp. 5–10. (An invited editorial piece co-authored with collaborators working on the *Nodes and Networks* collective experiments)
2. Barnett, H. (2019a) 'Being Other Than We Are...', *PUBLIC*, 31(59), pp. 158–169. (An invited peer reviewed essay for a special issue on *Interspecies Communication*)
3. Barnett, H. (2019b) 'Many-Headed: Co-creating with the Collective', in A. Adamatzky (ed.) *Slime mould in arts and architecture*. Denmark: River Publishers (River publishers series in biomedical engineering), pp. 13–37. (An invited peer reviewed book chapter for an anthology of creative slime mould research in art and architecture)
4. Barnett, H. (2022) 'The Physarum Experiments', *Antennae: The Journal of Nature in Visual Culture, Microbial Ecologies* (59), pp. 223–233. (A peer reviewed portfolio and essay in a special issue on *Microbial Ecologies*)
5. Barnett, H. (2023) 'Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life', in Anderson-Tempini, G. and Dupré, J. (2023) *Drawing Processes of Life*, Intellect Books. pp. 201–226. (An invited peer reviewed book chapter, contributing to interdisciplinary publication connecting art, biology and process philosophy).

B.3.1. Nodes and Networks: New York City
SciArt Magazine, August 2016, pp. 5–10.



NEW YORK CITY

NODES AND NETWORKS

what slime mold can show us about

collective behavior and city living

The many-headed slime mold, *Physarum polycephalum*, is a single-celled amoeboid organism which, when left to its own devices, forages around the forest floor quietly digesting rotting vegetation. Placed outside of its natural habitat—in scientific laboratories, design studios, and classrooms—it performs the role of a model organism, used to demonstrate biological computation, network efficiency, and collective decision-making. Impressive for what is essentially a bunch of cellular cytoplasm with no brain or sensory organs, slime mold operates at a capacity far greater than the sum of its individual parts.

The First International Physarum Transport Networks Workshop (PhysNet 2015) was hosted by Columbia University early in December 2015. This scientific workshop was dedicated to a wide spectrum of research on slime molds including the physics, cellular biology, and genetics of *Physarum polycephalum* as well as sessions on education and art. Inspired by this conference and the behaviors of the slime mold, a cross-disciplinary experiment spread throughout New York City at the same time, with the ultimate aim of testing human collective behaviors—how people interact and navigate in the city, how they problem-solve, and how they distribute information. Taking the behaviors of *Physarum polycephalum* as stimulus a team of artists, designers, and scientists came together to plan *Nodes and Networks*, a series of experi-

ments to explore the interconnections between biological, cultural, and social collective systems.

Nodes and Networks explored the themes of the workshop creatively from multidisciplinary perspectives by connecting the scientific conference attendees with local art and design communities. Experiments were based at the School of Visual Arts' BioArt Lab, the Metropolitan Museum's Media Lab, and public sites across the city. The collaborating team included artists, writers, architects, and designers working with biological systems and scientists from the fields of biophysics, ecology, genetics, and neuroscience. *Nodes and Networks* brought these many heads together to create lab experiments, participatory games, and tracking activities through a creative emergent process.

Here, some of the collaborators share their experiences working across disciplinary divides and with public participants in an open and exploratory process emphasizing mutual inquiry. Their perspectives cover collective creativity, citizen science, the relationships between biological and technological networks, and the challenge of trying to understand the subjective life experience of a simple single-celled organism.

— *The Nodes & Networks team*

Heather Barnett is an artist and educator with an interest in systems theory and collective behavior who has been working with slime mold as material, model, and metaphor since 2009. She is interested in the connections between emergent properties present within biological, social, and technological systems and in developing collaborative frameworks for art and science inquiry. She is Course Lecturer in the MA Art and Science at Central Saint Martins, University of the Arts London.



As an artist, my work engages directly with biological materials in the studio or laboratory and as a metaphor in participatory experiments. As a teacher, I am interested in creating the conditions for critical and creative learning to take place, without trying to control the outcomes. *Nodes and Networks* provided an opportunity to combine different methods of research with participatory arts practices, to explore the creative potential for bio/social models, and to create a collective “system of inquiry.” I wanted to build a self-organizing process, where everyone involved could contribute to the exploration, and to bring together different ways of engaging with the question of slime mold ‘intelligence’: from learning about its biology and the myriad of slime mold research, to working with it as a living material, to embodying its behaviors through following slime mold rules.

Some of the laboratory experiments we developed, which took place in the BioArt Lab at SVA, tested the organism’s decision-making skills—as people sought answers to some of life’s trickiest questions, such as which pair of shoes to buy, which life choice to make, or if God exists. From the sublime to the ridiculous and from the trivial to the existential, participants seeded Petri dishes with oats to indicate alternative choices and invited the slime mold to explore, its path divining the answer.

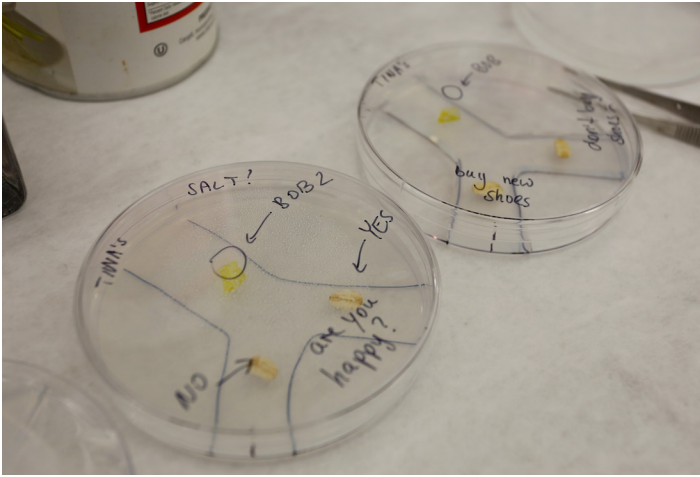
Other material experiments used the slime mold as an urban flaneur, its exploratory behavior used to model the changing character of the city. The five New York boroughs were cast in microbiology agar (to form a damp base for the slime mold to grow on) and topographic maps were created for the slime mold to navigate. Participants used wooden modelling materials to define urban areas (streets, boundaries, territories); oats were then added to represent attractive areas (parks, open spaces, community hubs) and chili powder used to represent negative elements of city living (environmental pollutants, high crime areas, areas of social neglect). As people looked at maps, selected materials, and talked about the city, they worked with their hands to visualize their conversations, be they about rising property prices, social unrest, the value of green spaces, or the process



COLLECTIVE CREATIVITY

Having been invited to contribute to the Physarum Network Workshop at Columbia I was keen to somehow connect the scientific community working with slime mold with others interested in biological models, but working within non-scientific fields. Through a cascade of local invitations, a small but eclectic team of people grew around the project, each sharing some interest in exploring how slime mold could relate to urban planning (it has successfully replicated the Tokyo transport system and many other mapping endeavors), collective decision-making (it can resolve navigational problems efficiently) and foraging behaviors (it displays intricate growth patterns when looking for food).





of gentrification. Given only a few parameters—such as basic growth behaviors, food preferences, and a range of building materials—groups created symbolic maps. As the slime mold grew, drawn to the attractants and avoiding the repellents, it became a live social commentator, giving biological shape to very human concerns about the urban environment.



Hans-Günther Döbereiner is Professor of Physics at Universität Bremen in Germany working on biological physics and, with his team, organized the scientific workshop PhysNet 2015. His group is interested in cellular motility of fibroblasts and the slime mold *Physarum polycephalum*,

in particular how foraging behavior is embodied in its extended transport network architecture and dynamics. *Physarum's* oscillating tubular network is capable of hydrodynamic computing. As such *Physarum* may serve as a non-neuronal model system for universal mechanisms of decision-making.

STEPPING OUT OF THE IVORY TOWER

In recent years, there has been an increasing openness from the scientific community to interface with art. Throughout interactions, a two-way feedback loop develops: artists dwell deeply into the scientific subject enabling maximum creativity, whilst scientists, confronted with unfamiliar artistic views of their subject, step out of their ivory tower, resulting in new questions and, often, surprising answers. Notable projects include *Not Invented by Nature* and *Synthetic Aesthetics*. Generally, interactions have a new quality not only between the

arts and sciences, but with other disciplines as well. Art and architecture have a long-standing common history, but only recently have interdisciplinary project teams worked together from the beginning of the process, resulting in more integrated planning and building. One spectacular example is the Wehrhahn-Linie Düsseldorf, where a whole subway line has been created in a concerted effort over a time span of 15 years.

In this spirit, and knowing Heather Barnett's previous work, I approached her to contribute to PhysNet 2015. Our initial discussion finally led to *Nodes and Networks*, a series of events scheduled around the Physarum Transport Network Workshop conference. Besides engaging with core participants, my students and I enjoyed pleasant interactions with local professionals and the general public. As a teacher, I was especially delighted with the feedback from Tobin Willms, a high school student from Montclair, New Jersey: "I thought the event was a great success! I learned a ton about an organism I did not even



know existed. It was a very interesting and great experience... I really enjoyed how interactive it was and that it was friendly to people who were not as involved in the scientific world."

As a scientist, I embraced the creative chaos that ensued through the deliberately loosely planned hackathon. With some amazement, I watched some of the individual and collective ideas take an ordered shape. My own contribution was to redo Heather's *Being Slime Mold* experiment with a modified set of local rules for the participants. Briefly, each person became an actor, as part of a giant 'slime mold', and was given a set of rules on how to behave. The question was how and in what way does collective behavior emerge from these individual rules? It was fun to see a group of people possessing some form of inertia in contrast to the highly viscous plasmodium

of a slime mold. Furthermore, there were considerably more “leading units” than one would observe in a real slime mold. These preliminary findings demonstrate that one can achieve results in two traditionally separated fields, i.e. cellular motility and human interactions, in simple environments. The difference in behavior points to a general model of interacting agents, with slime molds and humans representing extreme limits. Possible deep implications for models of decision-making are an exciting prospect. The interactive experience of *Nodes and Networks* and numerous discussions with colleagues have since led to the organization of a widely interdisciplinary lecture series on “Universal Properties of Decision-Making” at Universität Bremen, Germany.



Lior Zalmanson is an Internet behavior researcher, currently conducting postdoctoral studies at New York University exploring retention and commitment behaviors in online environments. His lab experiments follow people’s engagement and browsing patterns, especially

upon consuming creative content—for instance at video and music websites. He is also a new media artist working with crowdsourced art, where production includes the active mass participation of Internet users.

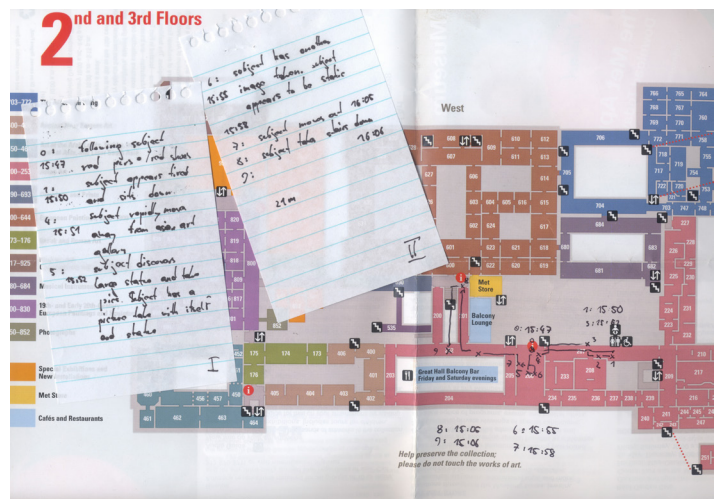
CULTURE FORAGING

My interest in both art and social sciences drew me to *Nodes and Networks* and its interdisciplinary “braintrust.” I tried to combine a little of both areas upon working and experimenting with the notion of navigation—a key concept in both human and slime mold behavior.

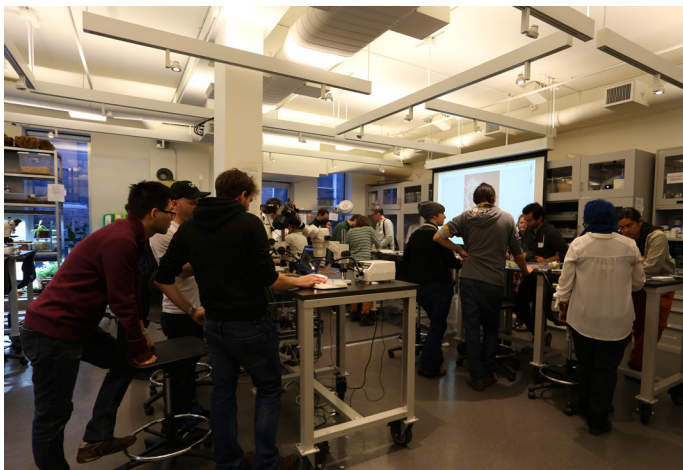
Slime molds have become notorious as organisms that can solve complicated labyrinths and find the shortest path between food sources. This is interesting to scientists and mathematicians as maze navigation can fall into the set of ‘NP-Complete problems’—in layman’s terms a set of problems that is characterized by having no simple or fast solutions. Typically the effort to solve them increases exponentially with the scale of the problem (in this case the size of the labyrinth), which makes it really difficult for computers to resolve them in a reasonable amount of time. The fact that such a “simple” organism can tackle such a problem has ignited other scientific interest in these special creatures. Relating back to online environments, the subject of navigation is no stranger to Internet researchers: we draw complex networks of

virtual realms, for example, when looking at how people browse websites and cyberspace.

For *Nodes and Networks* we created a twofold artistic experiment on navigation at the Metropolitan Museum of Art in New York City, working in collaboration with the MET Media Lab. For the first part, we 3D printed a model of the MET Asian Art Galleries—which are quite labyrinth-like—and distributed slime mold across the galleries with strategically placed food, thus hoping to reconstruct an “efficient” gallery route through the MET’s maze-topography. For the second part, we looked at the human aspects of gallery navigation. We asked twenty of our volunteers to assemble at the MET’s main hall. Each of them was asked to identify a museum visitor who “caught their eye” at the door and follow them for 30 minutes, whilst recording their path on a gallery map. Observing people at museums is not a new research strategy, with most large museums conducting similar research to observe human flow and behavior. But utilizing non-professional trackers, and asking them to form a one-sided connection with an unsuspecting individual visitor, created interesting observer-subject relationships and resulted in a variety of movement patterns and art-foraging stories. If most navigational research looks at “what is common” or “what is effi-



cient,” conducting this experiment revealed to us the beautiful variance, and often inefficiency, of human behavior. For example, some people in our sample walked through the museum as if they were treading in a sacred temple, slowly trying to take it all in; whilst others jogged through with their peers and friends, the museum merely providing an aesthetic background to their work or play dates. Within such an hedonic setting as the Metropolitan Museum of Art, the complexity of understanding navigation patterns emerged, offering interesting contrast to the patterns formed in more practical and survival-related contexts, such as the slime mold’s search for food.



Christine Marizzi

is an award-winning scientist and educator and currently Urban Barcode Project Manager at Cold Spring Harbor Laboratory’s DNA Learning Center in New York. With more than a decade in national and international science education, she dedicates her time, energy, and intellect to help students realize their greatest potential in STEM fields and provides traditionally underrepresented students with multiple entry points to academic and professional careers in STEM disciplines.



ENGAGING CITIZENS THROUGH HANDS-ON ACTIVITIES

The Citizen Science movement advocates an inclusion of non-specialists in the research process that demands interaction between citizens and researchers. On the institutional level, many initiatives have been developed by science centers, museums, and science

communication departments to bring people closer to the processes and questions of scientific inquiry through festivals, discussion platforms, TV shows, and science cafes. On the other hand a strong DIY, hacker, and maker scene is growing exponentially, with scientifically and technologically literate citizens challenging institutional ownership of the research process and influencing innovation. Science communication and engagement initiatives have made much progress in engaging non-scientific communities, but examples of dynamic connections being made between science and society are still rare.

The *Nodes and Network* workshop explored this by not only offering participants ways to participate, but also by including them from the beginning in the experimental design. Prior to the workshop, the invited core group brainstormed potential experiments, leaving room for the participating citizens (scientists and non-scientists) to work together on accepting, rejecting, or refining those ideas, as well as defining the outcomes valuable for both groups. This inclusion from an early stage is important to bridge the gap between citizen and scientific research.

The workshop is a great example of how people with different disciplinary expertise and interests can benefit greatly from working together. We hoped that participants would enjoy the workshop, which would allow them to carry out authentic slime mold research on topics of their choice, with opportunities to produce data and make discoveries along the way—as artists and scientists. Feedback from *Nodes and Network* participants overwhelmingly showed that our citizen scientists appreciated the ownership over their projects and the sense of “having fun while doing hands-on experiments”.



Oliver Kellhammer

is an ecological artist, activist, and writer as well as a part-time lecturer in sustainable systems at Parsons/The New School, New York. He is particularly interested in exploring non-human subjectivity and spends a lot of time with slime molds,

both in the rainforest of coastal British Columbia where he lives part-time and in his apartment in Alphabet City (NYC) where he raises them in Petri dishes.

ON SLIME MOLD SUBJECTIVITY

It is hard to imagine a life form more distinctly ‘other’ to us than the *Physarum polycephalum* slime mold, a humble yellowish blob we might encounter on a forest path

or creeping across the surface of a Petri dish. Yet this organism has the ability to beguile a remarkable variety of humans, from biophysicists, biologists, and mathematicians to urban planners and conceptual artists, with its fascinating displays of problem-solving and rudimentary social behavior. This was epitomized during *Nodes and Networks*, a multi-day suite of events, experiments, and discussions on all things *Physarum*.

Physarum's uncanny intelligence can be used to look at human problems, like how to map subway systems and road routes, via its surprising ability to connect nodes (oatmeal flakes) into networks (the paths it takes to get to them) in the most efficient way possible. With *Physarum* we can model our own sociality, our human interconnectedness, and yet as an organism it is completely alien to us—lacking even a rudimentary nervous system or any kind of centralized instrument of control like a brain. *Physarum* is not even a single individual, as such, but a swarm of nuclei that cooperate within a single superorganism, streaming through a continuum of shared protoplasm, like faces in a crowd.

Crowd behavior is something we humans recognize, which made me wonder about the question of intersubjectivity—the amorphous zone where our respective worlds might overlap. The *Physarum* experiences its perceptual world; we experience ours. We experience *Physarum* experiencing its perceptual world, in our perceptual world. And *Physarum* experiences us experiencing it, as it reacts to our contributions of oatmeal in its Petri dish, and all the other experiments we keep putting it through. Who knows what else it might be taking in? As a *Physarum* aficionado, I felt compelled to ask if our connection might go deeper.

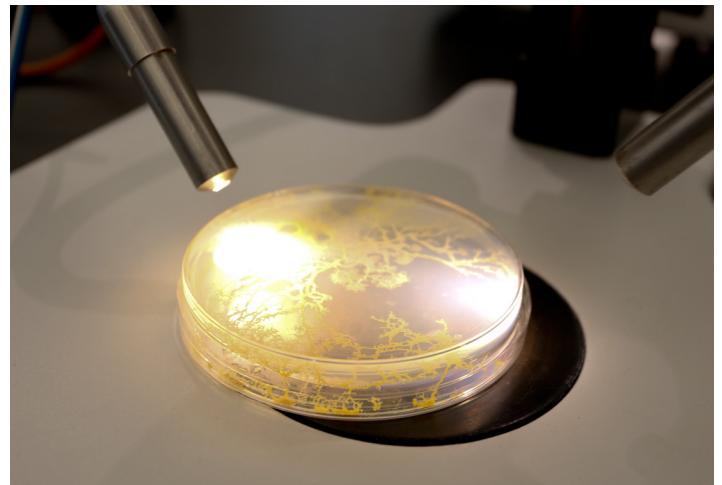
The German bio-semiotician, Jakob von Uexküll, had a word for an organism's perceptual world. He called it the '*Umwelt*'; the German translating literally as the "surrounding world" of a given subject, perceived and interacted with through its own organs. Von Uexküll visualized what the world might look like from the point of view of a host of creatures—ticks, sea urchins, jackdaws, flies, dogs, chickens—each from within its own *Umwelt*. So what of *Physarum's* *Umwelt*? It has no organs as such, but we can consider the signs, the bio-semiotic markers, that are important to it.

For example: bright light is a repellent and the streaming mass will move away. Conversely an oatmeal flake is an attractant and the mass will flow toward it. But what of the individual nuclei? They are the ones responding to the stimuli and propagating information through the group. Are they selves? And does it really matter? Perhaps the idea of "selfhood" is, to a large degree, in the eye of the beholder, important only to those of us who inhabit a human *Umwelt*. We can think of the *Physarum* as a self or as many intersubjective selves—a community

of perception, if you will. As multi-celled organisms, we too have a history of incorporating other selves into our corpus, like the single-celled organisms we long ago absorbed into our cells as organelles, or the symbiotic bacteria that thrive in our guts now. But perhaps we were the ones who got absorbed into something bigger?

So where do we draw the line? By cloning *Physarum* from a master culture in a biological supply house somewhere and shipping it all over, are we not also entangling ourselves in its collective *Umwelt*? Its nuclei can divide every eight to 10 hours so it's easy to imagine *Physarum* as a single super-subjectivity, oozing around the myriad Petri dishes in our science labs and classrooms all over the world.

Be that as it may, the *Umwelt* of the *Physarum* would likely be temporally and spatially nothing like our own. Yet what *Nodes and Networks* made clear is that we recognize in this simple organism a basic kinship, an aliveness, a "universal will to become"—despite its distinct alterity from our own morphological makeup. Witnessing the agency of this ignoble creeping blob as it follows its desires, avoids things that cause it suffering, and explores new territory, brings us deeper into the wonder that is our shared existence within this strange and exceptional set of circumstances we are all wound up in—here, as life, on this planet.



For more information and details on the Nodes and Networks project visit www.nodesandnetworks.com. Other collective experiments looking to biological systems as a model for social agency and creative endeavors are in the works for 2017, so watch out for Nodes and Networks coming to a city near you.

All photos courtesy of Jared Vaughan Davis, Heather Barnett & the Nodes and Networks team.

B.3.2. Being Other Than We Are...

in PUBLIC, Interspecies Communication 31(59), 2019, pp. 158–169.



BEING OTHER THAN WE ARE...

PREFACE

For a number of years, on a reasonably regular basis, I have challenged groups of people to test their capacity for collective coordination against that of a single-celled organism. The experiment, *Being Slime Mould*, invites a group of humans to operate as a superorganism, and sets them—it—tasks relating to navigation, communication, and cooperation. The aim of the exercise is to engage with some fundamental ontological rules of a nonhuman intelligent life form through playful participation.

Being (or becoming) slime mould is, of course, an impossibility; we can no more become slime mould than we can become badger or bat. The point of the experiment, therefore, is in the trying: the attempt to put aside human ego and individualism for a moment in order to shift perception towards other ways of seeing, feeling, and being. This article investigates diverse attempts taken to engage philosophically and experientially with the sensory subjectivities of other living entities. Through thought experiments and embodied actions, I investigate the motivations and methods of human endeavour to engage in being other than we are from the fields of ecology, post-humanities, speculative design, and philosophy.

BATS AND BADGERS: THINKING AND ACTING AS A RELATIONAL EXERCISE

In 1974, American philosopher Thomas Nagel wrote an essay exploring the problems he saw as inherent in the phenomenological understanding of subjective experience (and the mind-body problem in general).¹ “What Is It Like to Be a Bat?” wrangled with the limitations of comparative analogy in understanding sensory experience and, while contradictory in parts, generally recognized that empathy and imagination were required to build conceptual maps of alternative perceptual worlds. Nagel’s essay is an interesting thought experiment, a musing on the possibilities and challenges of trying to engage conceptually with nonhuman ontologies. The questions it raises—concerning *relatedness* and *otherness*—are pertinent to many current thinkers concerned with ecological and posthumanist philosophy. Writers such as Donna Haraway² and Timothy Morton³ are calling into question the human-centred position in exploring sensory subjectivities. Like Nagel, they suggest that increased empathy and imagination are needed to bridge perceptual divides and form a greater understanding of the “companion species”⁴ within our shared habitat.

Whilst speculation is useful in encouraging critical thinking, there is also a need for action. If we are to better know and care for our environs and the multitude of co-existing populations, we need to also take a directly experiential approach to the phenomenological understanding of otherness.

Attempts by humans to connect with nonhuman existence have a very long history. From early visualizations of hybrid beings to shamanistic practices calling on the beast within, we have always undertaken embodied modes of enquiry. To explore these modes within more contemporary practices, I draw on examples of diverse epistemological processes combining different forms of knowledge and experience. For example, courtesy of a Wellcome Trust public engagement grant in



FIG. 1 Thomas Thwaites connecting with goat kin on a Swiss hillside in *Goatman* (2016). Courtesy of the artist. Photo: Tim Bowditch.

2015, speculative designer Thomas Thwaites undertook an ontological journey into “goatness,” taking him to both research laboratories and Alpine hills. The resulting book, *Goat Man: How I Took a Holiday from Being Human*,⁵ offers a detailed account of the conceptual and practical process of enquiry. The text documents Thwaites’s work with a prosthetics lab (to alter his structural morphology), experiments with gastrointestinal processes (to facilitate the digestion of grass), and time spent in a sanctuary to better understand the goat psyche. Finally, kitted out and mentally prepared, he traveled to Switzerland to graze alongside goat “kin,” much to the bemusement of the herder who was “visibly amused by this totally ridiculous spectacle of an Englishman finding it extremely difficult to be an Alpine goat”⁶ (FIG.1).

Whether Thwaites can actually become a goat is not the real question in this quest. His investigation into “goatness” is, at its core, a piece of multidisciplinary design research that traverses fields of study: from neuroscience, anatomy, and microbiology, to art history, sociology, and psychology. His experiences offer the reader a vivid speculation on the complexity of what it is to be a goat, in physiological, social, and cultural terms. As an empathetic exercise, his endeavour could be seen as rather superficial—after all, he spent only three days in the direct company of the goats. But even within that time frame, his tacit understanding of kinship expanded through time spent aimlessly grazing and generally “being with” the herd. He also learnt the importance of observing social order.

The fact that it was physically easier for him to go uphill, rather than down, meant he “inadvertently committed a goat faux pax”⁷ by raising his own position on the hillside and, thereby, in the dominance hierarchy of the herd. He recalls the moment he became aware of his mistake: “I happen to look up from grazing and I realise that the entire herd is looking at me. It’s suddenly gotten very quiet. Everyone’s stopped chewing.”⁸

Moving to a far longer time frame of *companioning across species*, I turn to the project, *Being Caribou*,⁹ which maps the five-month long journey taken by biologist Karsten Heuer and film-maker Leanne Allison. The pair tracked tens of thousands of Porcupine caribou as they navigated a thousand mile annual migration route from their Yukon winter range to their Alaskan calving grounds and back. The aim of this incredible undertaking was to raise public awareness of the herd’s route to reach fertile lands, crossing territory destined for oil drilling. However, their co-migration revealed far greater territories traversed.

What started as a political action and scientific endeavour—to follow, study, and measure the herd’s movements—gradually shifted as the human trackers became assimilated into the life of the caribou. Over the five-month period, the trackers’ positions shifted from outside observers to fellow travellers as the decisions they took became based less on “scheming” and more on intuitive reasoning.¹⁰ Over time, a deeper empathy of the caribou grew as the human companions tacitly interpreted signs of danger, anticipated the herd’s movements, and intuitively understood the needs of the animals. After all, caribou and human were enduring the same harsh landscape, suffering the same scarcity of food, and encountering the same hungry bears:

Guided by forces and knowledge we’d never known existed, we had stumbled into a dimension that neither university education, religious teachings, nor anything else in our Western upbringing had taught. It had taken a while, but for a few brief weeks we’d become caribou: content in our suffering, secure in our insecurity, fully exercising the wildness that had been buried within us all along.¹¹

Through time spent in shared experience, a level of empathic understanding had evolved within the researchers, and they “found themselves on the cusp of a different way of knowing,”¹² one akin to what ecological philosopher, Timothy Morton, defines as *attunement*: “a living, dynamic relation with another being.”¹³ Acknowledging that the “other” in question can never be known directly or totally, Morton defines attunement as a relational exercise of entanglement, one based on accepting “an ontological jump between a thing and its parts.”¹⁴

To explore what attuned entanglement between human and nonhuman entities might mean in practice, I turn to Charles Foster’s psycho/bio/socio-philosophical enquiry. *Being a Beast*¹⁵ is a compilation of ten years’ worth of embodied experimentation that takes a directly empirical approach. The book traces Foster’s numerous attempts to “become” animal through processes of eating, living, breathing, shitting, and sniffing the world *as an other*. His “multispecies storytelling”¹⁶ provides an absurd yet insightful and provocative account of a series of committed phenomenological experiments, which see him scavenging for food and avoiding arrest (as an urban fox), sniffing his childrens’ excrement (as an otter), and being chased by hounds (as a deer). The most intriguing and involved chapter, and the most challenging to my human sensibilities, is the one related to “badgerness.” On a damp Welsh hillside, father and son camp out, dig a sett, get naked, and nestle against the wet earth in order to contemplate the sensorial world of this bristly kin. They even adopt a badger’s diet—the comparison between the relative culinary merits of earthworms from different parts of the country makes for particularly stomach-churning reading.

Foster takes his time in describing his experiences and the thinking he does while having them. As a thought experiment enacted, he considers the perceptual world of badgers by approximating his behaviour and his living conditions as closely as humanly possible to theirs: “Being a badger consisted simply in allowing the wood to do to us what it did to a badger; being there when it rained; keeping badgers’ hours; being cramped underground; letting the bluebells brush your face instead of your boots.”¹⁷ His enquiry is an earnest attempt to step outside of the comfort zone of humanness in order to think about the ontological existence of other creatures, although he fully acknowledges the “physiological fences keeping us out of the badger’s world.”¹⁸ Within this intellectual and experiential framework, Foster understands all too well that the experiment is hampered by his own subjective *umwelt*—the sensory, spatial, and temporal characteristics pertinent to his species-specific relationship with his environment.

Literally meaning “surrounding world,” *umwelt* relates to how different organisms understand and relate to their surroundings differently. Coined in 1934 by German biologist Jakob von Uexküll,¹⁹ the core concept recognizes that the subjective realities of all organisms exist at fundamentally different scales, and that moments in time, and the processing of information, do not operate within a single environment. Warning against “the widespread conviction that there is only one space and time for all living things,”²⁰ Uexküll understood coexisting entanglements. Likewise, in his cross-species speculations, Foster acknowledges the spatiotemporal barrier to any attempts of shared perceptual experience. He knows that the conceptual maps of his *umwelt* will always be bound by the limitations of the sensory equipment his species has evolved. The point of the exercise, and the enjoyment in its telling, is its self-knowing failure—utterly pointless in any practical terms, but meaningful in thinking imaginatively and empathically about another’s existence.

The subjects of scrutiny in these examples relate to creatures that hold a certain familiarity to us humans. Foster chose animals that share our habitat and are oft represented in literature.²¹ Thwaites chose a goat, not only for practical reasons,²² but also because of the historically utilitarian relationship

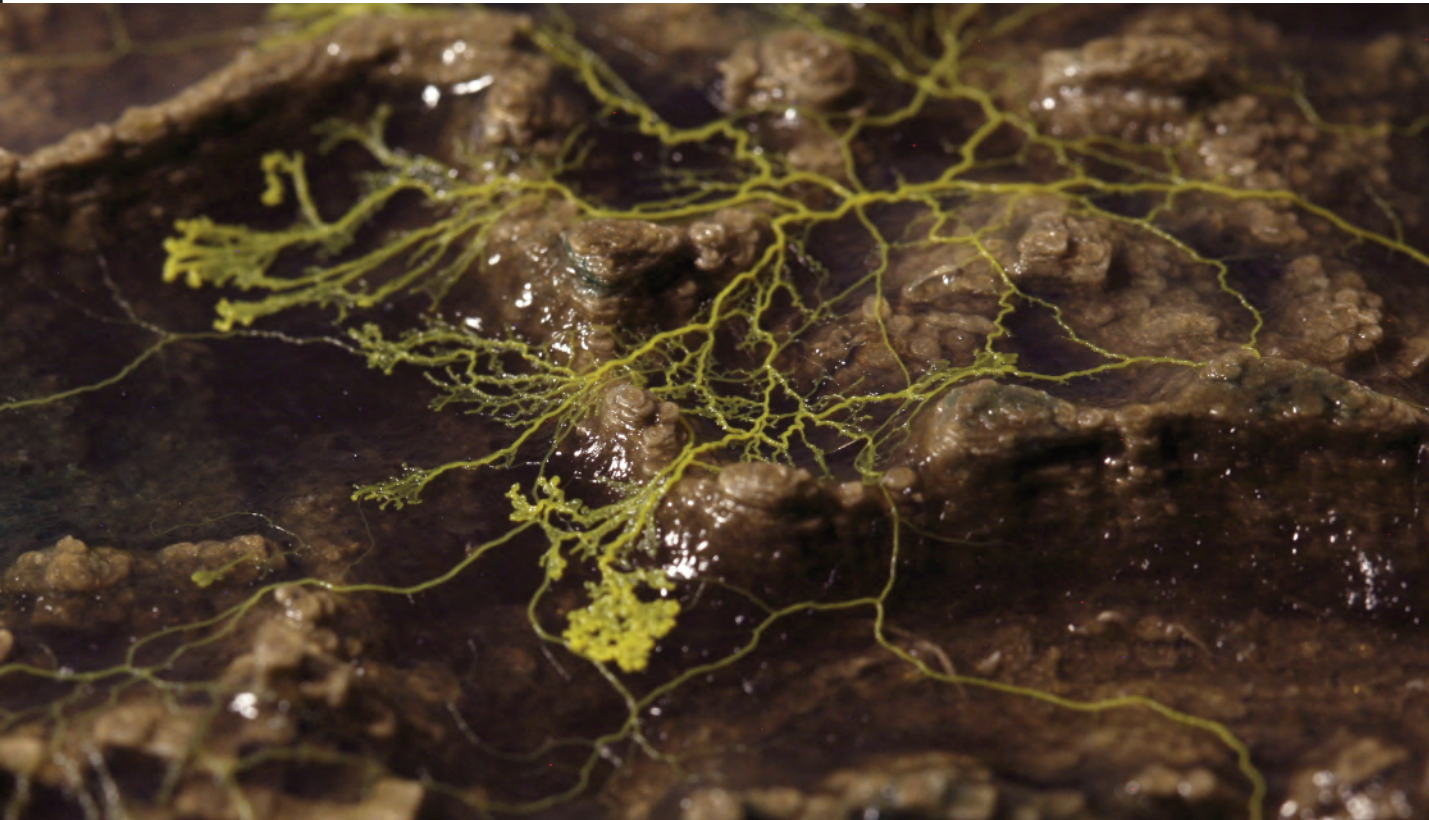


FIG. 2 Heather Barnett and ecoLogicStudio, *Resilient Topographies #1* (2017), depicting the slime mould, *Physarum polycephalum*, navigating its environment. Courtesy of the artists.

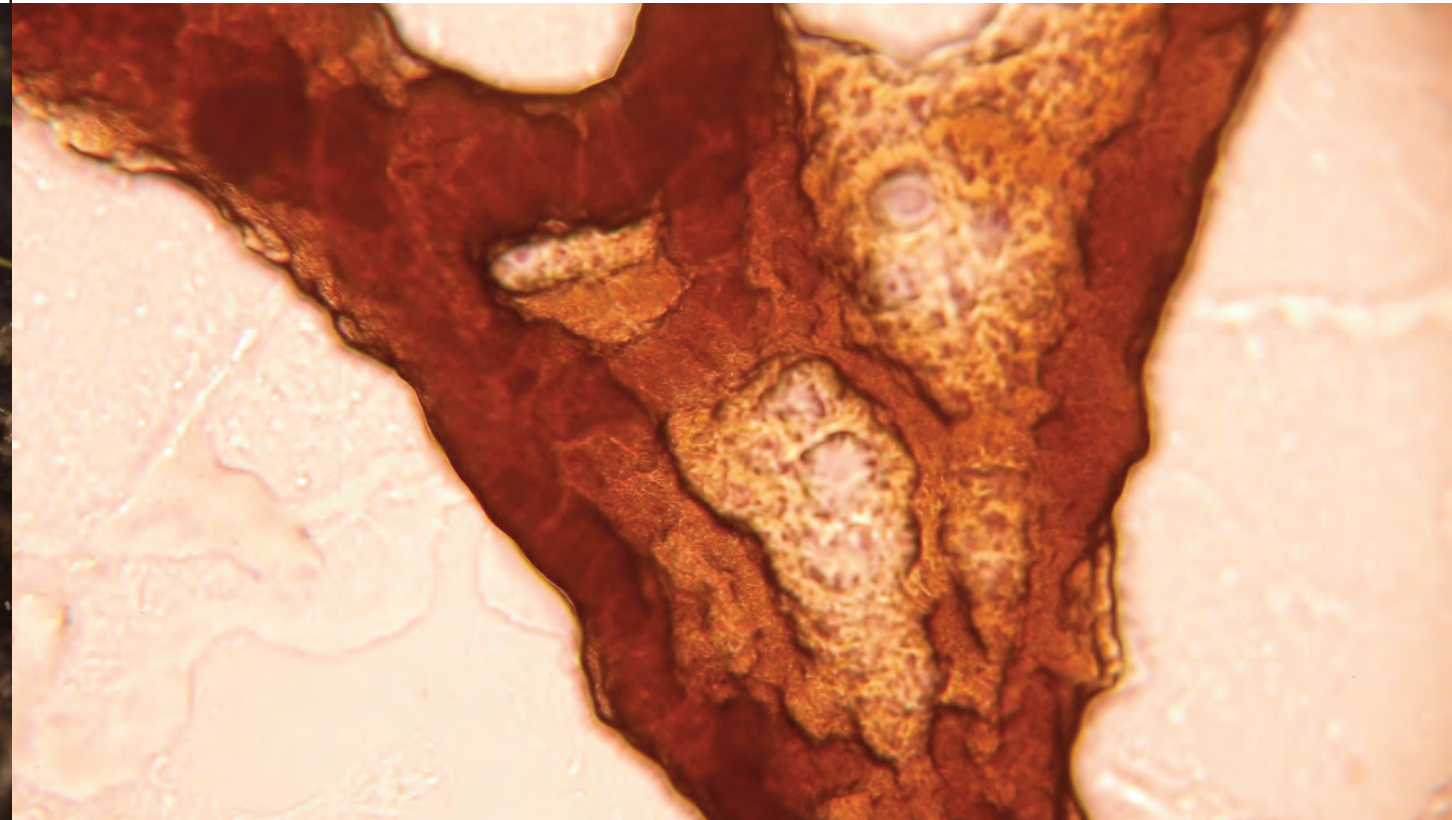


FIG. 3 The internal workings (protoplasmic streaming) within the many-headed slime mould, *Physarum polycephalum*. Microscope image x 400 magnification. Courtesy of the artist.

between goats and humans. Nagel chose a bat because of its position in between, as both familiar and perceptually different, presenting “a range of activity and a sensory apparatus so different from ours that the problem I want to pose is exceptionally vivid.”²³ They are all complex, multi-cellular organisms with which we have some form of relationship. They all generally share our *umwelt* within a certain tolerance of spatiotemporal scale.

My own form of ontological experimentation takes a far less familiar nonhuman subject, one that operates within a radically different sensory realm. The organism in question has no recognizable bodily similarities, plays no part in childhood stories, and has no functional relationship to humankind beyond the vast array of multi-disciplinary research employing the slime mould as a subject of study and as a model organism. It is a single-celled amoeba that creeps around the forest floor, digesting rotting vegetation and exploring its world through a feedback loop of chemical sensing.

BEYOND ANIMAL: BEING (BECOMING) SLIME MOULD

As an artist, I have been engaged with the slime mould, *Physarum polycephalum* (FIG. 2), for almost a decade, working with the organism as material, model, and metaphor.²⁴ Made up of millions of self-similar cells all operating as one single entity, this many-headed²⁵ amoeba possesses no brain or sensory organs and bears no morphological resemblance to us (FIG. 3). Yet, its behaviours share some familiar characteristics—it demonstrates a primitive form of intelligence, high-level network optimisation capabilities, and the ability to anticipate events and learn from its environment.²⁶

In addition to creating time-lapse films, building installations, and running workshops,²⁷ my practice working with slime mould also involves a form of embodied modeling—an invitation for people to follow behavioural rules in order to better understand how this organism can operate far beyond the sum of its parts. The participatory experiment, *Being Slime Mould*, started in 2013 as a public engagement exercise,²⁸ a means for people to explore the inner workings of the slime mould through a form of enactment. By extracting some fundamental biological behaviours and applying them to a different realm, *Being Slime Mould* amplifies slime mould “logic” to human scale. Since



FIG. 4 *Being Slime Mould* experiments (clockwise from top left): The Conference, Malmö, 2013; The Metropolitan Museum of Art, New York, 2016; Collective Motion Conference, Uppsala, 2016; Open Embodiments Conference, Tuscon, Arizona, 2015. Courtesy of the artist.

this first occasion, slime mould rules have been applied in a range of settings and with different groups. For example, I have entreated a group of corporates to navigate non-hierarchical organisational systems; tested the self-organisational capacity of a 300-strong conference audience; and challenged the distributed intelligence of a group of collective behaviour scientists to embody the same mechanisms that they observe and measure on a daily basis in their own research (FIG. 4). The “rules” given relate to the morphological states, information distribution mechanisms, and sensory communication strategies of the organism. The group is instructed to operate as a single mass entity, always in physical contact, though dynamic and able to constantly reshape. Communication is permitted through oscillations only. Therefore, verbal communication is forbidden and a physical means of distributing information must be improvised. Frequently, attractants and repellents are placed within the environment for the super-cell to encounter, communicating environmental information through the organisms’ body mass.²⁹

The intention of the experiment is not to capture data or measure behavioural response, nor to demonstrate any specific hypothesis. It is a playful invitation to attune to slime mould sensibilities, to think through embodied experience, and to reflect on that experience. As with Thwaites’s and Foster’s experiments, the point of the exercise is in the attempt to dispense with the ontological burden of humanness for a short while and to embrace a shift into otherness.

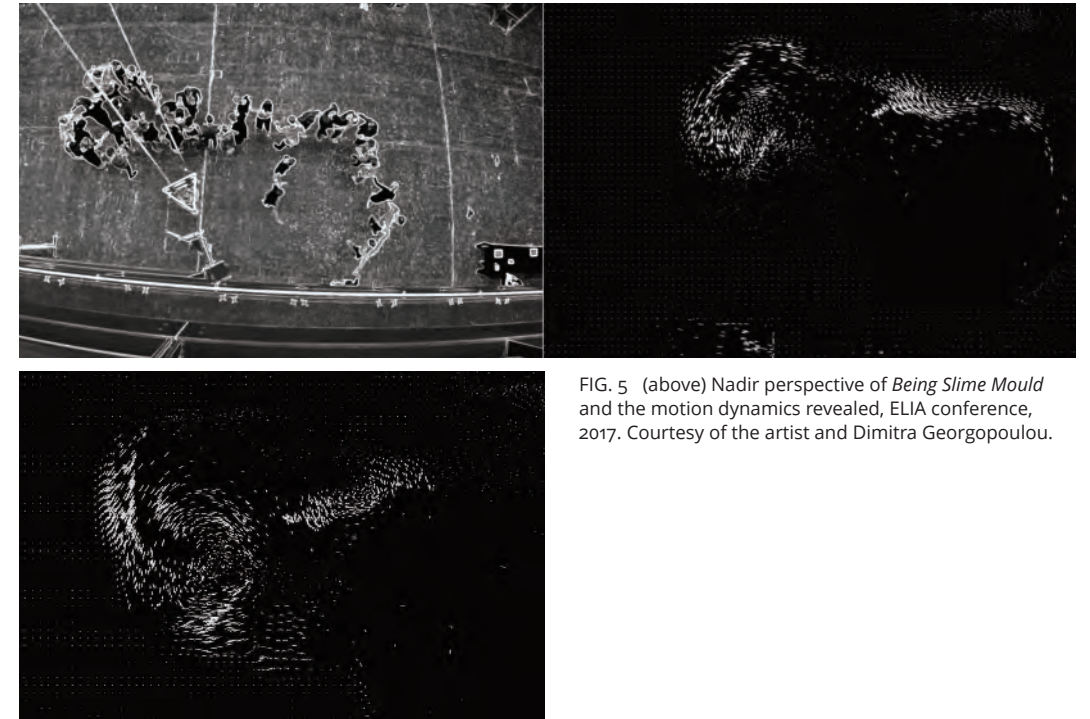


FIG. 5 (above) Nadir perspective of *Being Slime Mould* and the motion dynamics revealed, ELIA conference, 2017. Courtesy of the artist and Dimitra Georgopoulou.

FIG. 6 Motion dynamics of global super-cell *Being Slime Mould*, ELIA conference, 2017. Courtesy of the artist and Dimitra Georgopoulou.

How people interpret the rules of *Being Slime Mould* also depends on the highly individualized nature of human character. Each iteration of the experiment has been followed by open discussion, encouraging people to reflect on their observations. It has been interesting to observe how individuals relate to the organism, and what associations they each bring to that experience from their own contexts and with their own preoccupations. Discussion has drawn out many points of connection: comparing slime mould communication to other comparative biological models; relating the network formation to that of larger scale urban contexts; and exploring definitions of intelligence across species and scales. In some contexts, the slime mould has related to human organizational systems or other collective experiences, including the biological and phenomenological processes of learning.

Specifically, at an arts education conference at the University of the Arts London in 2017,³⁰ I delivered a keynote presentation offering the slime mould as a metaphorical model to interrogate institutional knowledge systems and hierarchical structures within education. The talk was punctuated with an embodied experiment, putting some of the ideas discussed into action, with the entire delegation invited to participate as a “many-headed super-cell” to test collective communication strategies. As it emerged from the lecture theatre, the “human slime mould” was filmed both from above (to track the collective motion) and on the ground (to capture individual reactions). These recordings provided differing perspectives as more than sixty people milled around trying to tune



FIG. 7 Human dynamics within the super-cell, *Being Slime Mould*, ELIA conference, 2017. Courtesy of the artist. Image: Gareth Johnson.

into their neighbour-cells. From above, the application of a “motion field” to highlight the movement of the whole “organism” revealed the global motion dynamics of the entire organism—the individual lost within the mass of complex movements and spatial negotiations (FIGs. 5 and 6).³¹ From within the mass, a different story unfolded as each person responded uniquely to the task (FIG. 7), with some looking slightly uncomfortable, some totally immersed, and others choosing to break the rules by talking to their neighbours or taking a global view of what was happening.

Upon returning to the relative human safety of the lecture theatre, participants were asked to record their observations and note the strategies they adopted and the challenges they encountered (FIG.8). As might be expected, responses varied hugely. Some noted that they found being in physical contact with strangers awkward or stressful, while others found it relaxing or comforting, or their position shifted having started the exercise feeling uncertain and then gradually relaxing into it. For some it was a challenge not to communicate through language, while for others silence provided a welcome break from the usual pressures to articulate meaning through words. And some commented on the sensory aesthetics of the experience operating as part of a self-organizing mass, with one participant noting that:

For me it was very important to look at my feet—although I was in intensive contact with other bodies the look downwards brought me a slight feeling of private space and awareness of my own body and the bodies of the others. I perceived the others, their breath, their skin and clothes—it was a bit like dancing without anybody leading the choreography.³²

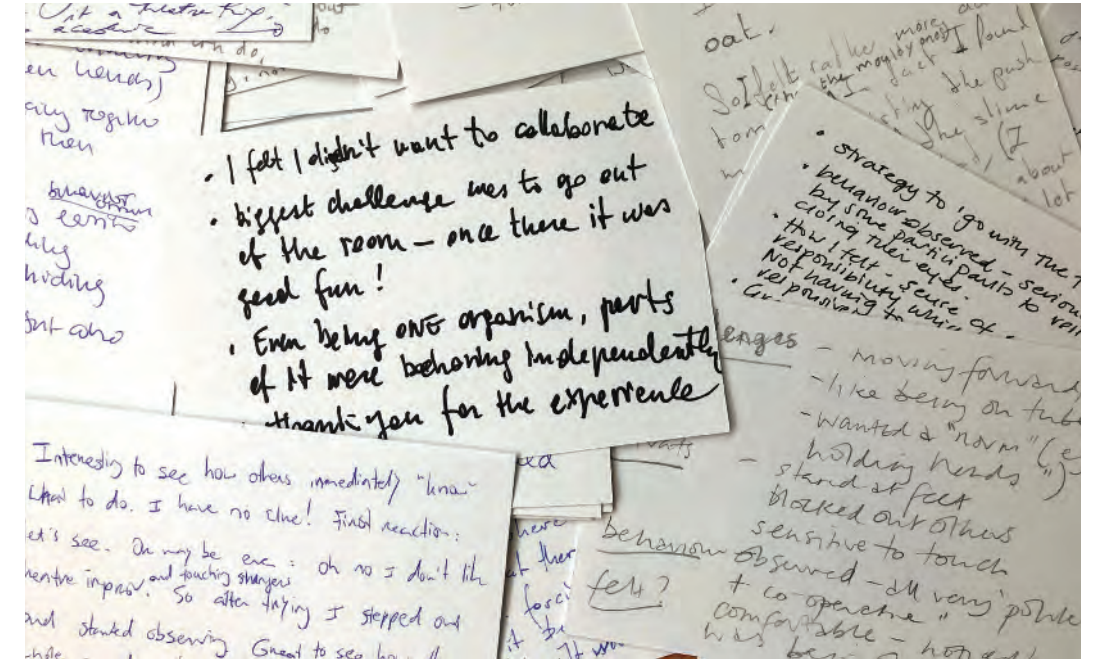


FIG. 8 Written observations of *Being Slime Mould* from ELIA conference, London, July 2017. Courtesy of the artist.

Whatever the individual interpretation, the intention with this mode of playful modeling was to provide a means to think about systems through direct experience and to form insights about nonhuman behaviour—be it a biological organism or an institutional system—by embodying some fundamental principles and intuiting that understanding through enactment and reflection. *Being Slime Mould* asks people to tune in to a different mode of communicating, of co-existing and cooperating, shifting perspective from that of an individualistic and egocentric human to that of an altogether different form of intelligent life.

BEING INCLUSIVE: EMBRACING THE MANY-HEADED

The ontological experiments discussed in this essay, including my own attempts to create a human collective super-cell, are “thought actions,” each setting out to create the conditions for an embodied experience. The tacit learning to be gained from direct engagement and the critical reflection that can follow can help us better understand the complexities of interspecies entanglements. If we challenge our physiological and sensorial experience of our habitat, we might, for some moments, imagine we can transcend otherness. To do so may allow us to attune to a more conducive state of ecological thinking, a moment when we do not treat nonhumans “like uninvited guests”³³ in our human-centric world. By acknowledging multiple perspectives, which overlap and intersect in space and time, we can realign our position. We can question, we can tune in, and we can take note. In this associative space of shifting subjectivities that cross species and scales, we can hold up these “others” as a mirror to ourselves.

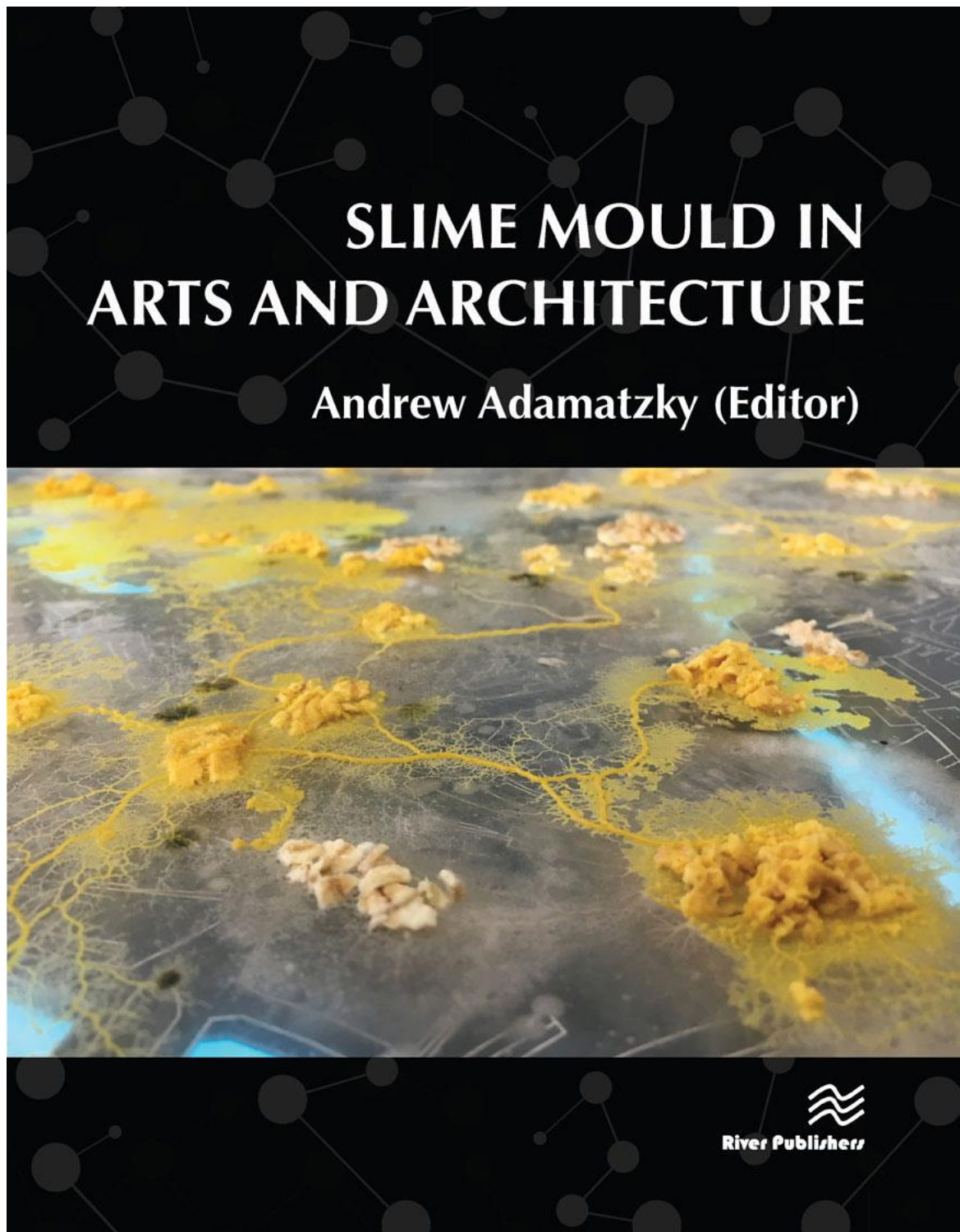
The slime mould—alien, yet relatable in so many ways—offers us a multitude of layers through which we can view ourselves and others simultaneously. To attune (in thoughts and actions) to an array of companion species allows us to recognize the vast flow of diverse sensing, signaling, perceiving, and responding that intercuts our interconnected worlds. Of course, the paradox is that the very act of attempting to be *nonhuman* merely amplifies *humanness* in all its complex forms. But rather than trying to deny anthropomorphic tendencies, the experiments described here acknowledge the impossibility of that avoidance. In his treatise, *Being Ecological*, Morton argues that to achieve a higher order of ecological awareness, a certain level of anthropomorphism is required “since even if you intend not to be, there you are, a human, relating in whatever human way you are relating to whatever other lifeform.”³⁴ As one *Being Slime Mould* participant at the ELIA conference commented, “By trying to be non-human you start thinking about what is human. You are being confronted with your ‘humanness’ whatever that may be.”³⁵

How far into nonhuman territory we are prepared to extend inclusion is yet to be seen in how we enact our entangled ecological thinking in the world, but I would argue that we should look beyond that which is purely relatable in physiological and sensorial terms. We should also embrace organisms that offer us altogether other ways of being. Dynamic in physical form, (mostly) egalitarian and cooperative, and highly responsive to the nuanced information flows in its environment, the finely *attuned* slime mould may provide us with an exemplar “eco-sensory” model of how we can be in this world.

NOTES

- 1 Thomas Nagel, “What Is It Like to Be a Bat?” *The Philosophical Review* 83.4 (October 1974): 435-450.
- 2 Haraway has contributed much to current thinking about interspecies and ecological thinking in relation to the epoch of the anthropocene, most recently in *Staying with the Trouble: Making Kin in the Chthulucene* (Durham and London: Duke University Press, 2016).
- 3 Timothy Morton’s writing connects object-oriented ontology and ecological philosophy. His most recent texts include *Being Ecological* (Cambridge, MA: MIT Press, 2018) and *Dark Ecology* (New York: Columbia University Press, 2016).
- 4 Haraway coined this term in her book, *The Companion Species Manifesto: Dogs, People, and Significant Otherness* (Chicago: University of Chicago Press, 2003).
- 5 Thomas Thwaites, *Goatman: How I Took a Holiday from Being Human*. (New York: Princeton Architectural Press, 2016).
- 6 *Ibid.*, 156.
- 7 *Ibid.*, 176.
- 8 *Ibid.*
- 9 Karsten Heuer, *Being Caribou* (Seattle, WA: Mountaineers Books, 2005).
- 10 *Ibid.*, 84.
- 11 *Ibid.*, 222.
- 12 *Ibid.*, cover blurb.
- 13 Morton, *Being Ecological*, 139.
- 14 *Ibid.*, 101.
- 15 Charles Foster, *Being a Beast* (New York: Metropolitan Books, 2016).
- 16 This is another term commonly associated with the writing of Donna Haraway.
- 17 Foster, 47.
- 18 *Ibid.*
- 19 Jakob von Uexküll, *A Stroll Through the Worlds of Animals and Men* (1934).
- 20 *Ibid.*, 327.
- 21 Some of this literature is written with significant anthropomorphism: think of Beatrix Potters’s tweed-wearing badger in *Tales from the Riverbank*, or the extensive list of fictional badgers in myth, poetry, and literature cited on Wikipedia: https://en.wikipedia.org/wiki/List_of_fictional_badgers.
- 22 Originally Thwaites proposed to become an elephant but changed his mind to pursue goatness instead.
- 23 Nagel, 438.
- 24 The multi-faceted methods of artistic research are discussed in Heather Barnett, “A Malleable Metaphor: *Physarum polycephalum* as Artistic and Educational Medium,” in the proceedings of The First International Workshop on Physarum Transport Networks (May 2016): [dx.doi.org/10.4108/eai.3-12-2015.2262479](https://doi.org/10.4108/eai.3-12-2015.2262479).
- 25 *Polycephalum* translates literally into “many headed.”
- 26 There are over 50,000 published articles on slime mould cited on Google Scholar from diverse fields of research including biophysics, computing, bioacoustics, robotics, urban design, philosophy, and management studies, to name but a few.
- 27 To see work from *The Physarum Experiments* project, please visit: <http://heatherbarnett.co.uk/work/the-physarum-experiments>. The wider work will not be discussed in the context of this essay.
- 28 *Being Slime Mould* was originally conceived by Heather Barnett with Daniel Grushkin, and “performed” as part of the exhibition, *Biodesign: On the Cross Pollination of Nature, Science and Creativity* at the Nieuwe Instituut in Rotterdam in September 2013.
- 29 Markers are identified in the environment, or people are cast as oats (attractant) or salt (repellent).
- 30 ELIA conference presentation, *Experiments in Elasticity*, Central Saint Martins, University of the Arts London, 2017. Information online: <https://www.elia-artschools.org/activities/elia-academy/programme/plenary-sessions>.
- 31 The “motion field” program was developed by Dimitra Georgopoulou and Heather Barnett as part of a collaborative residency, *Animal Collectives*, with SHOAL Group at Swansea University, 2017. See: <http://heatherbarnett.co.uk/work/animal-collectives/>.
- 32 Anonymous hand-written observations collected at the ELIA conference, 2017.
- 33 Morton, *Being Ecological*, 96.
- 34 *Ibid.*, 111.
- 35 ELIA observations.

B.3.3. Many-Headed: Co-creating with the Collective
in *Slime mould in arts and architecture*, 2019, pp. 13–37.



3

Many-Headed: Co-creating with the Collective

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In this essay, I critically reflect on my artistic encounters with the slime mould, *Physarum polycephalum*. Since 2008, this non-neuronally intelligent organism has provided stimulus for diverse creative enquiries and speculative actions, including time-lapse studies (testing and revealing behaviours), objects and installations (for public exhibition), and embodied encounters (inviting groups of people to enact slime mould rules). Focussing discussion on selected projects and processes developed over the past decade, connecting public audiences with slime mould behaviours, I will address the organism as a working material to be manipulated, coerced, or encouraged to ‘perform’ and as a conceptual model, to explore notions of embodied intelligence between human and nonhuman entities.

Whilst looking directly at the collective behaviour of the organism, the narrative also addresses wider processes of human enquiry, the slime mould as a vehicle for curiosity and discovery. The concept of *polycephalism* – many-headedness – here relates not only to the internal cellular mechanisms of the slime mould, but to the methods developed to connect diverse ways of thinking and working in a process of co-enquiry. My artistic practice is a literal and symbolic investigation of information distribution mechanisms, diverse knowledge systems, and collective intelligence – an invitation for interdisciplinary and interspecies encounters. This essay is as much about the emergent properties of the creative process and the interactions between disciplinary approaches, as it is a study of the properties of slime mould itself.

3.1 Introduction

As an artist I have long enjoyed working with biological materials, having previously cultured my own skin bacteria, built growing installations employing the tropisms of seeds, and experimented with the camouflage capabilities of cuttlefish¹. Working with living matter is a balance between artistic intent (my ideal impositions) and biological behaviour (the characteristics inherent in the organism). To a great extent, this logic can be applied to any process of making, a negotiation between artistic aspiration and material property – form cannot be imposed upon a piece of marble but must be carved out with consideration to its inherent structures and imperfections. This need to understand material properties is, however, more prevalent when working with a living system, where the material in question possesses agency and exists within its own ‘*umwelt*’²; and where motivations, perceptions, and intentions relate to vastly different needs. Here, the subjective reality of the organism operates through unfamiliar sensory and communication mechanisms and notions of artistic control and authorship are called into question.

My first encounter with slime mould took place in July 2008 when I was gifted a live culture after a visit to the laboratory of Dr Simon Park at the University of Surrey³. It was a speculative meeting to share common interests in microorganisms and exchange creative activity across art and science. As I prepared to leave, aware that I had worked with living organisms before, he handed me a petri dish containing a small yellow blob. The only care instructions given were that it liked to be kept dark and damp and its favourite food was porridge oats. Simon had a hunch I would be intrigued by the structure and behaviour of slime mould. He wasn’t wrong.

The organism in the petri dish was *Physarum polycephalum* – literally meaning the ‘many headed’ slime mould – one of over 700 known species of slime mould, a single-celled organism that lives a relatively quiet existence digesting rotting vegetation in temperate woodland. A slime mould cell may contain thousands, often millions, of individual nuclei, fused together and operating as one collective entity. Within the organism, a channel of protoplasmic streaming⁴ distributes nutrients across the cell mass,

¹ A portfolio of previous works can be found on my website at: www.heatherbarnett.co.uk

² Literally translates as ‘surrounding world’ – a term coined by German biologist Jakob von Uexküll relating to how an organism perceives its environment uniquely and subjectively.

³ Simon Park has worked for many years at the intersection of microbiology and art. Many of his experimental practices can be viewed on his blog *Exploring the Invisible*.

⁴ A regular rhythmic oscillation within a vein-like structure. It is within this pulsing mechanism that many of slime mould’s achievements are believed to lie.

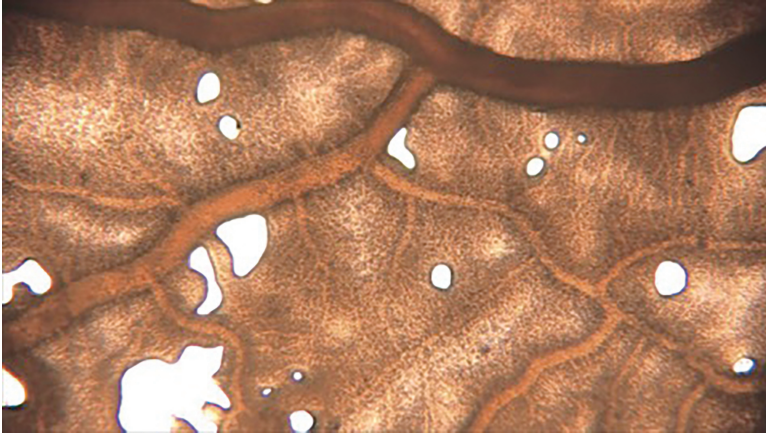


Figure 3.1 Protoplasmic streaming within *Physarum polycephalum*.

as well as communicating valuable chemical information about environmental conditions (Figure 3.1). It has built-in mechanisms enabling it to compute a range of cost/benefit trade efficiencies and allowing it to make variable decisions without a brain. The slime mould has demonstrated that it can recognise pattern by anticipating events and is entirely self-organising, with no centralised control system – purely a mass of cellular cytoplasm operating at a capacity far greater than the sum of its parts.

3.2 The *Physarum* Experiments

Safely housed in a shoebox and growing on a moist substrate, I began the rather ad hoc process of empirical enquiry and discovery. My new studio pet was fed on an eclectic diet of foodstuffs, including decaying plant matter and desiccated insects (Figure 3.2). Its material environment contained a range of materials with different ‘moisture holding’ properties and its housing ranged in size and material form, from laboratory glassware to Tupperware. My initial thoughts were that I could get the organism to draw for me, that I would lay down a trail of food and that the slime mould would dutifully follow, creating intricate growth patterns along the way. It soon transpired, however, that this was a naïve assumption.

I ground down oats and boiled them into a paste, which was then piped into shapes and lines. I placed food on pieces of felt and moved them around, following the growth trajectories through a combination of time-lapse photography and stop frame animation. This was an intuitive process of

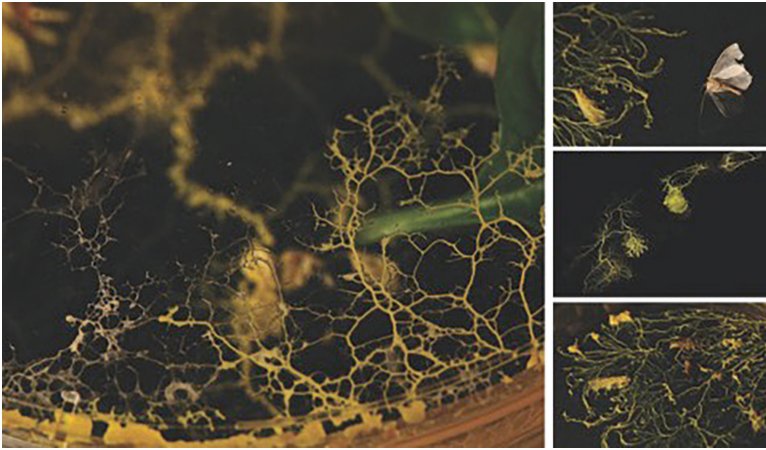


Figure 3.2 Early culinary experiments with *P. polycephalum*.

trial and error in intervention and observation, learning from the organism's response to given stimuli. Through this process, it became apparent that any ideas I had of imposing my own aesthetic sensibilities on the organism were not necessarily compatible with the organism's own desires. Rather than trying to coerce the slime mould into doing what I wanted, it was clear that I needed to work with its inherent properties instead, to understand its fundamental needs and behaviours and use them as a starting point for experimentation. If this 'collaboration' was going to go anywhere, I needed to work with the slime mould on its own terms.

Hence, a process of enquiry followed with a meandering trajectory, exploring to what extent I could affect the organism's behaviour. By understanding its motivations, intentions or reactions, I could learn how far I could control or influence its growth and pattern formation. My early time-lapse studies lacked consistency. Without an automated set up to capture the pace of growth – I simply took a photograph manually when I could – the results were haphazard, with time frames shifting at irregular intervals (Barnett, 2008). Whilst these early studies had low production values and lacked aesthetic 'flow', they provided enough visual feedback to indicate that something interesting was going on, that the organism would respond to given cues and exhibit novel behaviours (Figure 3.3).

As my time-lapse techniques improved, the organisms' behaviours began to reveal themselves more clearly through my interventions. For example, in *Study No. 011: observation of growth until resources are depleted*

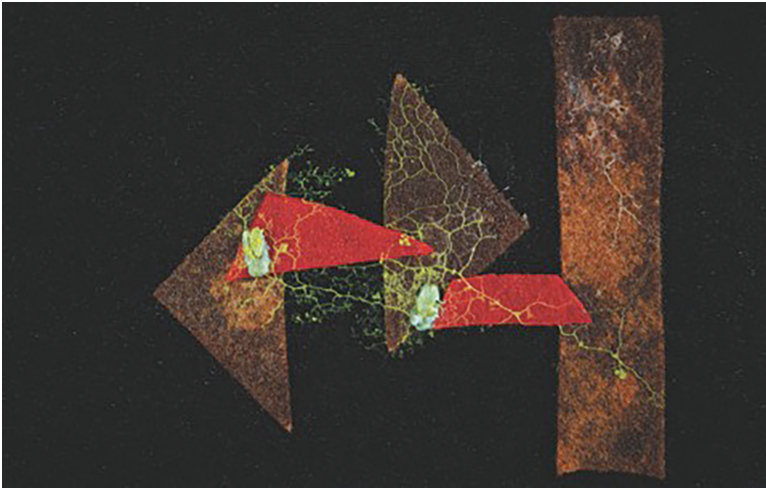


Figure 3.3 Film still from *The Physarum Experiments, Study No: 008 (2009)*.

(Barnett, 2009), having fed on a pile of porridge oats, the slime mould went off exploring in two directions simultaneously. At one point, the two branches grew towards one another, but before they collided, the growth slowed, paused and then reversed direction. Somehow the slime mould knew it was already there and should divert energies into exploring new territory elsewhere – a point of recognition, decision and action (Figure 3.4). I was impressed that an organism with no brain or sensory organs could map its environment in such an efficient manner and operate with seeming intention.

What then developed was a process of influence and observation; I would encourage growth with attractants, or discourage with repellents, and note the responding behaviours and structures. The artistic process became one of ‘creating the conditions for something interesting to happen’ and then observing the outcomes, choosing to intervene (or not) depending on what I was exploring. Over time, I have created a number of time-lapse studies exploring navigational abilities, interspecies encounters, problem-solving strategies and pattern generation (Barnett, 2018). Within these studies, my role became that of instigator rather than sole author. Whilst I could predict certain behaviours, I could not control the outcomes. What ensued became an on-going ‘collaboration’, a process of negotiation between an artist and a single-celled organism.

As I continued to create scenarios and environments to test the slime mould’s abilities, I began reading up on other studies and a vast world of



Figure 3.4 Growth Studies (digital prints) - from *The Physarum Experiments, Study No: 011* (2009).

research began to unfold. I discovered that slime moulds could find the shortest route through a maze (demonstrating a primitive form of intelligence) (Nakagaki), could form efficient networks between food sources (replicating all manner of networks whilst doing it), and that they possessed the capacity for memory (Saigusa). The transport network experiment (Tero), whereby the slime mould replicated the Japanese railway system surrounding Tokyo, spawned a whole host of further navigational enterprises for the slime mould, including mapping myriad other transport systems, migration routes, drug-trafficking routes, and evacuation pathways. These notable experiments had translated from academic journals to editorial features and online blogs. Other modes of enquiry were less widely available, residing within highly specialised academic journals. On a recent search, Google Scholar cited 59,000 published academic papers on slime mould⁵, a great many heads from diverse disciplines asking different questions of this simple yet complex organism.

In addition to the many feats of computational navigation and memory cited in scientific research, slime mould has inspired those working in sectors as diverse as arts, humanities, industrial design, and philosophy. For example, its network formation has informed new structural designs for

⁵On entering the search terms “slime mold OR slime mould” to capture both American and British spellings (note that this is English language texts only).

partition walls in Airbus' planes (Rhodes); used as a speculative model for resource distribution networks within urban design speculations (ecoLogic-Studio); and employed in philosophical discussion on the nature of cognition and decision-making in nonhuman forms of life (Shaviro). It was not only *Physarum polycephalum* that featured as a model organism. Other species of slime mould also provided a rich territory for enquiry, most notably the cellular slime mould *Dictyostelium*, with research ranging from studies on aggregation, motility and altruism by renowned biologists such as John Bonner (2010) (Durstun), to experimental research using the organism in the context of human healthcare (Huber and O'Day) and agricultural ecology (Amaroli, 2015).

As I developed my own image-making techniques, I also turned to the early films of Percy Smith for inspiration. A naturalist, inventor and pioneering filmmaker working in the early 20th century, Smith's vision and innovative cinematographic techniques captured the character of a broad range of natural systems, including slime mould as seen in his 1931 classic *Secrets Of Nature – Magic Myxies* (Smith). Some of my experiments also took inspiration directly from the scientific literature. As homage to Nakagaki's maze experiment, which demonstrated primitive intelligence, I built a three-dimensional model of the maze for the slime mould to explore (Barnett, 2013). In the scientific experiment researchers filled a maze with pieces of plasmodium, which spread and conjoined into a single mass cell. Food was then added at two points and the organism was observed as it contracted to form a thick tubular network connecting the two nutrient sources. The organism retreated from empty areas of the maze and adapted its morphology to form a single pathway, choosing from four possible solutions. The experiment was repeated several times, a significant number resulting in the slime mould selecting the shortest and most efficient route. Rather than replicate the scientific experiment to rationalise networks I was interested to observe the slime mould making arbitrary decisions at each turn to find its own path through the maze (Figure 3.5).

A range of exhibition outputs stemmed from these early *Physarum Experiments* including digital prints of growth studies, time-lapse films and sculptural objects (such as the maze), which could house a living sculpture – though at a top speed of 1-cm growth per hour observing living slime mould requires extreme patience. However, the amplified pace of time-lapse films in accompaniment in exhibition can help connect viewers with the mechanisms of the organism and reveal its potential, albeit imperceptible, growth trajectories.

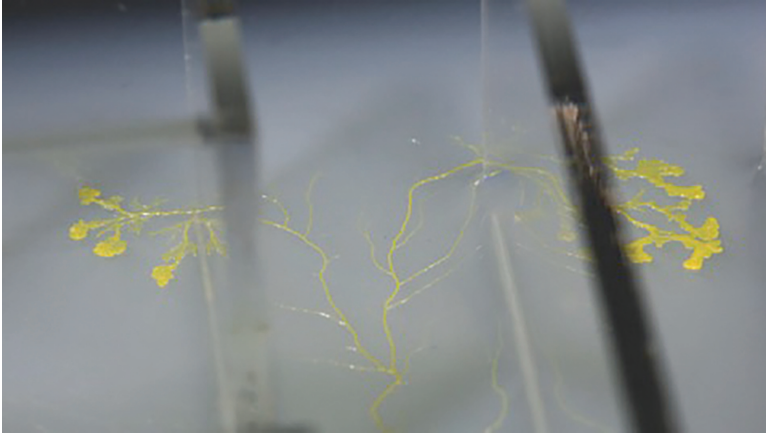


Figure 3.5 Film still from *The Physarum Experiments, Study No: 019 The Maze* (2013).

As I worked in the studio, getting to know my new ‘collaborator’ and discovering a world of enquiry through the research papers and articles, I posted every time-lapse study I made online, irrespective of its seeming success. I wanted the process of experimentation to be transparent and open, and I also wanted to connect with others curious about the behaviours of this organism, so one month after being given my first slime mould, I set up an online network, The Slime Mould Collective (slimoco), as a way to pool interest, share research and connect experimental practices. It was important that the network operated across disciplinary boundaries and beyond academic walls – a democratic knowledge space where professors and students, designers and scientists, enthusiasts and the simply curious, could engage on a level footing. There was also a subtext to the network, which was to see who would find it and how knowledge of it would spread through the existing online networks and search engines. After all the World Wide Web operates on similar principles of emergence as does the slime mould: namely, local interactions, pattern recognition and feedback loops, with no overriding control mechanism (Johnson, p. 22) – a self-organising platform for knowledge exchange, with all participants equal agents in the system. To date, the network has facilitated international exchanges, distributed collective knowledge and experience, helped experimental problems be solved, fostered collaborations and instigated many slime mould swaps.

Over the past ten years, through working in the studio, undertaking desk research and interacting with other slime mould researchers, practitioners and enthusiasts, I have developed a range of experimental practices, which explore slime mould behaviour and engage audiences with the questions that this organism raises. Through a range of techniques including film making, photography, print-making, sculpture, installation, interactive media, workshop design and participatory experiments I have tried to draw attention to the intriguing mechanisms of this natural phenomenon through creative and collective action.

3.3 Encounters and Interactions

The intention with *The Physarum Experiments* has never been to ‘represent nature’ – though that is a perfectly valid pursuit and inevitably forms a part of what I do – but to ‘work with’ a natural system that is little known to the general public, often overlooked and not fully understood (even by the scientists who have spent years studying it). This process of working with a living system can be incredibly time consuming (most time-lapse studies take several days to shoot and several more to edit) and involves a certain amount of uncertainty (until the hundreds, sometimes thousands, of individual still images are composited as a video I never really know if I have captured anything interesting). Similar to the latent image of an analogue photograph emerging in the developer bath, the time-lapse reveals what has been imperceptible in real time observation at the point of rendering.

A primary motivation to make artworks, or create experiences for audiences, is to encourage people to look at and to think about things I find interesting or important. This may seem a selfish pursuit, but in very simplistic terms it is at the core of any artist’s agenda, to draw attention to things that others may not notice. In presenting works from *The Physarum Experiments* in public exhibition, wherever possible I aim to translate some aspects of the essence of slime mould, a gradual reveal of the organism’s behaviour, and bring an element of individual discovery. Every exhibition aims to present an opportunity for interspecies encounters.

One example of bringing different strategies together is the exhibition *BioDesign* (2013), curated by William Myers and held at the Neu Museum in Rotterdam. For this presentation a trio of works was developed to engage viewers with the slime mould through observation, simulation and enactment.

Exhibited under the name of slimoco, as a collaborative endeavour⁶, I brought together various elements intended to encourage close observation and interaction.

The first element comprised a selection of time-lapse studies from *The Physarum Experiments*. This showreel presented a range of slime mould behaviours including moments of open exploration, rationalisation, decision-making, retreat and self-recognition. Behaviour was not made explicit, but could be deciphered by the viewer. The second element encouraged viewers to interact directly with a computational simulation of slime mould networking behaviour⁷. As people entered the gallery, a motion sensor located their presence and mapped them onto a screen – each visitor becoming a virtual food node for the digital slime mould to ‘consume’. As it explored its screen domain, the simulated slime mould located the food nodes, joined the dots and formed a network between the visitors in the gallery. As viewers moved, their positions were tracked in real time on screen. Albeit slowly, viewers became connected by the virtual organism and could test the dynamic network formed between human and digital agents (Figure 3.6).

Whilst the simulation went some way to engage viewers with the underlying mechanisms of slime mould behaviour, the computational simulation took reference away from its biological source. I wanted to find a way to directly address the biological effects of the behavioural rules. A third element was therefore developed to push the viewer further in trying to understand slime mould existence through a process of ‘enactment’, a way to directly experience something of ‘slimemouldness’ and explore how an organism can self-organise and cooperate from very simple elements. Devised initially in collaboration with Daniel Grushkin⁸, some rules of behaviour were extracted from *Physarum polycephalum* and applied to a participatory exploratory experiment. Much discussion was had about how to form a dynamic supercell network where individuals could be held within an adaptive membrane⁹,

⁶slimoco (The Slime Mould Collective) has also been used as an umbrella name for public exhibitions where several members of the network and/or external collaborators have co-produced outputs.

⁷The interactive piece was developed from a model of slime mould provided by computational scientist, Jeff Jones, and reprogrammed as an interactive installation by digital artist, Alex May.

⁸Daniel Grushkin is a science journalist and co-founder of Genspace, the first community laboratory, in Brooklyn, New York.

⁹A system of yellow ropes was used in this first iteration of Being Slime Mould, which could connect and disconnect to form an adaptive network, but never used since as they were far too distracting.



Figure 3.6 Gallery installation view of slime mould simulation, *Biodesign*, New Museum (2013).

how people would be permitted to communicate, and to establish what level of instructions should be given for them to understand the task at hand.

The experiment took place twice: once on the opening night within the museum and again the following day outside the museum in a tree-lined park. Both experiments were followed by filmmakers Jasper Sharp and Tim Grabham, who were shooting for the feature length slime mould documentary, *The Creeping Garden* (2014). The task for the group (a random collection of strangers on each occasion) was to navigate their environment as a single collective body, to locate food sources (giant oats) and form an efficient network (a competition against slime mould network optimisation). The experiment that took place within the building experienced some issues with bottlenecks forming, and enforcing the rules of behaviour proved quite challenging – perhaps exacerbated by a few drinks consumed on the opening night – but there was some attempt made by the group to collectively organise, communicate and cooperate, with partial success (Figure 3.7).

The next day passers-by were bribed with a specially commissioned slime mould T-shirt and the promise of beer¹⁰ and, once a group was formed, the strangers were set the task of navigating a park populated with multiple obstacles (trees). The rules of *Being Slime Mould* on this occasion maintained the need for a *constant physical connection between ‘cells’*, though this should

¹⁰We replaced oats with beer as an attractant for the effective recruitment of members of the public on a busy Saturday afternoon.



Figure 3.7 Daniel Grushkin explaining the rules of Being Slime Mould on the opening night of *Biodesign*, New Museum (2013).



Figure 3.8 Being Slime Mould enactment, public experiment, *Biodesign*, New Museum (2013).

be dynamic and not fixed, and *no speaking*, the slime mould communicating through some form of improvised oscillation. The task here was to *locate a food source* (beer) and *distribute resources* across the network to nourish all parts of the cell (Figure 3.8). The experiment lasted around 15 minutes and there was clearly some evidence of problem-solving in navigating around obstacles and reaching attractants whilst maintaining a collective and cohesive body, and in the end, everybody got a beer.

Clearly, *Being Slime Mould* is not a scientific experiment. It is not intended to prove a hypothesis or demonstrate anything measurable. In many ways the experiment is set up to fail, in that humans cannot ‘be’ slime mould. It is a knowingly impossible task. The point of the exercise, therefore, is in the trying – the attempt to let go of deeply held human traits for a short period of time – by following some fundamental rules of an ‘other’ life form. By setting a few simple rules, directing the mode of connecting, communicating and decision-making, complex behaviours can emerge.

In many ways, the most interesting outcome of *Being Slime Mould* is the discussion that follows the experiment. On this run, as people drank the beer they had collectively located and distributed, they reflected on what they had just experienced and shared their observations. Depending on their background they tuned in to different interpretations: a biologist compared the chemical signalling of slime mould to the quorum sensing of bacteria; a psychologist observed the range of human responses to the task, that some people lead and others followed; and an urban design student enquired whether we were trying to engender social agency in the group by thinking about how we relate to our environment as a collective entity.

Since this first attempt at *Being Slime Mould*, the exploratory experiment has evolved, adapting to different groups and situations. The slime mould has proved to be a malleable metaphor for exploring ideas ranging from communication strategies and organisational systems, to social agency and distributed intelligence. Through each iteration the framework remains the same – applying some simple ‘logic’ of nonhuman collective behaviour to a group of humans – but the specifics change depending on context. Notable examples include: entreating a group of digitally orientated corporates to navigate a conference room of a Mayfair hotel¹¹; testing the self-organisational capacity of a largely Swedish audience interested in biomimicry¹²; sensory explorations with a small but committed group in the Arizona desert¹³; challenging a group of collective behaviour scientists to embody the same mechanisms that they observe and measure in their own research¹⁴; and looking at slime mould through an educational lens (learning being a biological and phenomenological endeavour)¹⁵ (Figure 3.9).

¹¹ After lunch slot on Day 1 of the Financial Times Innovate Conference 2014.

¹² At The Conference in Malmö with approximately 300 people, the largest group yet, 2015.

¹³ Programmed off site on the first evening of the Open Embodiments Conference, Tuscon, 2015.

¹⁴ At the Collective Motion Conference 2016 in Uppsala, Sweden.

¹⁵ ELIA conference keynote presentation, University of the Arts London, 2017.



Figure 3.9 Being Slime Mould experiments (various).

By embodying some fundamental rules of slime mould the experiment invites people to act first and think second, to enact and then reflect on the experience of attempting to shift ontological perspective. In many ways, this organism is utterly alien to us, yet by possessing traits that we can relate to (such as learning, memory, and problem-solving), it somehow resonates. Beyond observation or measurable analysis, to embody an experiment is to learn through direct experience. Much of my participatory work encourages tacit, rather than purely explicit, learning to recognise diverse forms of knowledge. Including material thinking and embodied cognition, I aim to create opportunities for people to explore through doing, whether in the studio, the gallery or the park.

3.4 Playful Pedagogies

My own material experiments in the studio are very much ‘with’ the organism, learning from direct experience, and sharing the process of intervention and observation with others. My practice as an artist has co-evolved over the years with my practice as a teacher¹⁶, each informing the other. Hence,

¹⁶I have been involved in community arts and formal education since 1992. I am currently Pathway Leader on the MA Art and Science at Central Saint Martins (University of the Arts

workshops and educational activities have always played an important role in what I do as an artist. From science museums to floating cinemas, and from arts festivals to community laboratories, I have facilitated numerous workshops and participatory experiments bringing different groups of people into creative contact with the slime mould¹⁷. The aim of these activities is threefold: for people to engage with the organism as a living subject to observe (an interesting specimen of non-neuronal intelligence – ‘isn’t it fascinating?’), an object of enquiry (a system of knowledge for research – ‘what questions are being asked of it?’) and, thirdly, a model for examining larger questions of communication and cooperation (a comparative model – ‘how do we relate to it?’).

In workshops, the intention is not to present a prescribed view of the organism or to ‘instruct’ a lesson, but to use the slime mould as a vehicle for creative and critical exploration. Whilst people need to have a certain amount of information at their disposal in order to be able to engage meaningfully with the organism conceptually or experimentally, I am not in the business of science communication. The workshops aim to be associative rather than didactic.

An introductory preamble should equip a group with some fundamental knowledge about the organisms’ behaviour – for example, its morphology, function, communication mechanism and motivation – so that they can then design their own practical experiment. Questions embedded within the experimental design may relate to navigational abilities, foraging behaviour, pattern formation, or problem-solving; or people may simply wish to provide an interesting habitat for it to explore. The format of one workshop invites participants to create an experimental environment for the slime mould to explore within a small petri dish. They build into the circular arena with coloured felt, pipe cleaners, filter papers and other absorbent materials (to create ideal levels of humidity within which the slime mould can flourish). Water is added and a selection of attractants and/or repellents¹⁸, and then finally slime mould is introduced, transferred from a parent culture via a miniature cookie cutter. The tools people are given are purposely simple and require tactile manipulation, an invitation to explore haptically and, most importantly, playfully. As anyone who makes anything knows, the physical activity of

London), a Higher Education Academy National Teaching Fellow, and led the Broad Vision art/science research and learning project at University of Westminster from 2010–2015.

¹⁷I estimate that, in the past ten years, over 3000 people have participated in some form of slime mould related workshop, encounter or participatory experiment that I have facilitated.

¹⁸Attractants include oats, pasta, rice and flour; repellents include salt, chilli and lemon.

manipulating materials engages just enough of the brain to free up associative cognition¹⁹. It is important for creative thinking that participants don't overly predetermine the outcomes, but allow ideas to coalesce and emerge. From the same base materials diverse experimental environments are designed, from elaborately intricate networks to functionally experimental platforms, some intended for open exploration, others attempting to test a particular hypothesis about how the slime mould will respond to the conditions set. At the end of a workshop participants are invited to take their new pet home, given care instructions²⁰ and encouraged to share any results on slimoco (The Slime Mould Collective).

The social aspect is also important in any workshop situation, the bringing together of people from different disciplines, ages, and backgrounds and providing a context in which they can exchange ideas, converse as they make, and share moments of individual discovery (Figure 3.10). This combination of knowledge exchange and interdisciplinary interaction has gone on to form



Figure 3.10 Observing protoplasmic streaming, BLAST workshop (2015).

¹⁹Think about how many writers are regular walkers or how many ideas you've had in the shower.

²⁰Care instructions include acknowledging the nomadic nature of slime mould and its need to move house regularly, its preference for dark and damp conditions, and ideal diet of porridge oats; as well as instructions on safe disposal of slime mould if it is neglected and doesn't survive.

the basis for extended workshops and situated collective experiments, which cross borders of knowledge, discipline, and practice.

3.5 Collective Experiments

In recent years I have been developing a series of expanded workshops which use the slime mould as a starting point to explore other networked systems across species and scales – a form of bio/social collective experiment. Each situation responds to a specific set of conditions: a conference, an urban environment, a specific context, and/or a core question. Here, I reference a few examples which demonstrate the iterative and adaptive process of co-enquiry and share some of the methods and practices developed.

3.5.1 Nodes and Networks

In 2015 I was invited to contribute to a scientific conference, a three-day workshop on *Physarum* Transport Networks to be held at Columbia University in New York City. The invitation came from Professor Hans-Günther Döbereiner²¹, a biophysicist working with slime mould, based at the University of Bremen. Whilst the scientific field of slime mould research already operates across the domains of biology, physics, mathematics and computer science, the event organisers were also keen to include educational and art practices in the proceedings. I was more than happy to contribute to the conference and engage with the scientific research, but also wanted to connect the academic delegation with the city's art and science community²². Thinking about slime mould transport networks in the context of New York City, a framework was established for exploring the city as a superorganism, a collective interconnected body of networks and information channels. Organisms such as slime mould offer intriguing models to test how ideas spread, how group decisions are made and how communities evolve.

Taking the behaviours of *Physarum polycephalum* as stimulus, a multi-disciplinary team was recruited, comprised of artists, writers, architects and designers working with biological systems, and scientists from the fields of biophysics, ecology, genetics, and neuroscience. Together we devised a

²¹The Döbereiner group are interested in the biological physics of cellular systems and soft matter. In vivo studies of animal cells and slime molds are combined with in vitro investigations of model membrane systems.

²²Having previously delivered talks and workshops at Genspace community laboratory and contributed to exhibitions such as Cut/Paste/Grow at The Observatory in Brooklyn.

series of experiments to explore the interconnections between biological, cultural, and social collective systems and invited public participation for a marathon day of activities which took place at the BioArt Lab (School of Visual Art), in Central Park, and in The Metropolitan Museum of Art (in collaboration with MET Media Lab). The nature of the experiments varied. Material exploration in the laboratory used attractants and repellents as a means to create social maps of the New York boroughs, exploring subjects of pollution, crime or gentrification (Figure 3.11). Modelling experiments played out in Central Park, adapting the rules of *Being Slime Mould* to affect motivation, communication, and collective coordination. Finally, The Metropolitan Museum of Art provided a human petri dish for us to conduct a series of cultural foraging experiments tracking human behaviour in the galleries (whilst back in the lab the slime mould was exploring a scaled down 3D model of the same territory).

Nodes and Networks (Barnett et al., 2016) provided an opportunity to combine different methods of research with participatory art practices, situated in a specific location and context. Through a partially self-organising process, everyone involved could explore different ways of thinking about



Figure 3.11 Social mapping with *Physarum polycephalum*, *Nodes and Networks*, New York City (2015).

networked intelligences and collectively contribute knowledge and experience. The project brought many heads together to create novel ideas through a creative emergent process.

3.5.2 Swarm/Cell/City

Other collective experiments have addressed specific traits and mechanisms of the slime mould. In September 2017, working in collaboration with performance art duo *plan b*²³, I ran an extended workshop at Art Laboratory Berlin (ALB) as complement to the exhibition *Nonhuman Networks*²⁴. A participatory collective experiment in art, performance and biology, *Swarm | Cell | City* invited participants to view the local urban area through the nonhuman perspective of *Physarum polycephalum*. Using the local topography around ALB as inspiration, we ran a series of experiments exploring mapping mechanisms, spatial awareness and stigmergic²⁵ marking of territory. In practice this involved creating maps for the slime mould to navigate, mapping our own trails using GPS trackers (Figure 3.12), devising cooperative nonverbal navigation techniques, and developing a biosemiotic system of communicative chalk markings. All activities were documented and the subsequent film formed part of the exhibition (Barnett and plan b).

Within the group I recall a biochemist, an anthropologist, a choreographer, several artists, and a writer – typical of most slime mould workshops, where disparate disciplinary backgrounds centre around the organism from individual points of interest. Questions raised during the two days were plentiful and cannot be fully recorded here, but to give a flavour discussion ranged from curiosity about pigmentation and colour indicators, through questions of epigenetics and learned behaviours passing through generations of cell lines, to philosophical musings on a duty of care towards nonhuman organisms and recognition of the slime mould's performance (sacrifice)

²³plan b are Sophia New & Daniel Belasco Rogers. See more of their work at: <http://planbperformance.net/>

²⁴Nonhuman Networks featured work by Saša Spačal, Mirjan Švagelj & Anil Podgornik, and various works from *The Physarum Experiments*. The exhibition, the last in the Nonhuman Subjectivities series spanning two years, ended with a three day international conference exploring themes of *Nonhuman Agents in Art, Culture and Theory*, November 2017.

²⁵Stigmergy is a process by which an organism leaves a trace in its environment which affects the behaviour of other organisms, such as ant pheromone, termite mudballs or slime mould membrane.

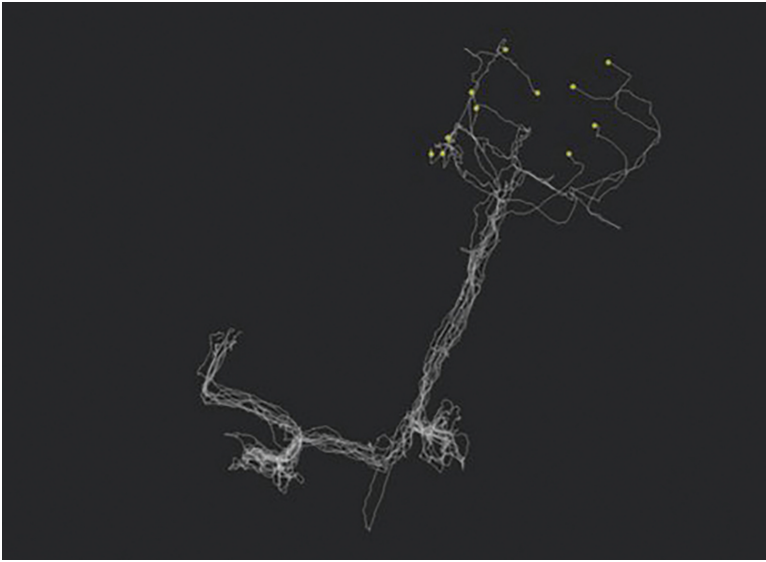


Figure 3.12 Trail making in *Swarm | Cell | City* workshop (2017).

for our intellectual curiosity²⁶. Throughout the workshop, the slime mould operated as a springboard for sympoetic working²⁷ – collectively exploring, experiencing and discovering.

This model of co-enquiry has been developed and applied to a number of different situated experiments, many relating to urban contexts. For example, *Crowd Control* (Barnett et al., 2017), a month-long interdisciplinary residency with Arebyte Gallery in Hackney Wick, an area of East London which has undergone a great environmental and economic change in recent years. Connecting visual, digital and performance art practices with contemporary scientific research, law and urban design, the project explored the mechanisms of collective behaviour across biological, urban and social scales. Other examples include *Spatial Negotiations*, an on-going collaboration with choreographer Emma Ribbing²⁸, using the slime mould

²⁶At the end of the workshop one participant dedicated a poem by Emily Dickenson to the slime mould in recognition of its contribution to our enquiry.

²⁷‘Sympoesis’ meaning creating together, coined by scholar and community activist Beth Dempster in relation to self-organising human systems.

²⁸Emma and I met at the Collective Motion conference in Uppsala, Sweden, whilst facilitating embodied experiments with a group of collective behaviour scientists. She was the most dynamic cell in the Being Slime Mould experiment and inspired the idea of working with dancers.

as a stimulus for movement research. And at the time of writing, a number of bio/urban exploratory experiments are planned to take place in Munich²⁹ and Amsterdam³⁰, each a platform for shifting perspective from a human-centric position to embrace the multitude of interspecies interconnections.

3.6 Polycephalism

Like the slime mould I move with seeming intention, yet very little of what has been described here has been in any way predefined. Most of the practices – the time-lapse studies, the workshops, the gallery installations, the absurd experiments (Bates) – stem from a creative process which has unfolded over time... each encounter or experience leading to new learning, novel insights and hybrid forms of enquiry. Not to exhaust the metaphor (too much), but my own creative process has operated much in the same way as slime mould behaves. I forage until I find a resource (a piece of research which acts as a stimulus or tells me something new; a collaborator who shares a common interest but who brings a different perspective; or an observation of a novel behaviour in the organism itself), and then form connections between these nodes. New projects and ideas coalesce and the exploration continues, finding other bodies of knowledge or points of connection along the way. In the ten years I have been ‘working with’ slime mould, my practice has evolved in new directions and with unpredictable results – the creative process operating as its own many-headed emergent system.

The notion that we ‘can learn from semi-intelligent slime’ (Barnett, 2014) should not be taken too literally, but there is much to be gained from taking note of its capabilities. As an artist, the slime mould offers me a set of aesthetic properties to work with (it is beautiful), a fascinating subject (it is biologically and behaviourally peculiar) and a muse (it raises many interesting ontological and epistemological questions). The slime mould is, for me, a story telling device – a vehicle through which we can appreciate the complexity of natural systems. As a model organism, it offers myriad curiosities to investigate questions of decision-making, distributed intelligence, and computation. In pragmatic terms, it provides an amenable body for experimentation, without the need for ethical approval or high-level

²⁹Part of {un}[split]Micro Performance and Macro Matters Science & Art Festival in Munich, September 2018.

³⁰Part of Open Set’s Summer School and Labs Programme, Fluid Rhythms: Urban Networks and Living Patterns, August 2018–February 2019.

laboratory controls. Yet the achievements of this single-celled organism do raise some important philosophical questions about how we recognise and engage with other forms of intelligent life. As for assessing a duty of care to my living co-worker, I have come to realise that the relationship here, between artist and organism, is far from ‘collaborative’, but more akin to a form of benevolent slavery (though consensus on who is a slave to who is yet to be reached).

In his manifesto, intended for artists working with living systems, Mark Dion (2000) sets out a series of guiding principles addressing questions of responsibility, anthropomorphism, nostalgia, representation, and language. He proposes that “The objective of the best art and science is not to strip nature of wonder but to embrace it. Knowledge and poetry are not in conflict.” (ibid, p. 240). Like Dion, my work seeks to explore how we understand and interrelate with nature through different forms of knowledge. My creative explorations with slime mould are less directly ‘about’ the organism, but far more about ‘ideas of’ the organism: how we view and interpret and make sense of its way of being in the world we share with it. The intention is to hold up this organism as a subject, a model and a metaphor, to capture curiosity and to offer up discussion around different ways of knowing and different ways of being, “as humanity cannot be separated from nature, so our conception of nature cannot be said to stand outside of culture and society. We construct and are constructed by nature” (ibid, p. 239).

The argument for ‘polycephalism’ is, therefore, not that we should become more like slime mould, but that we should become more acutely aware of other living systems around us (and within us for that matter)– a reminder that ‘we are always inside an environment with a group of other interdependent living organisms’ (Manacorda, p. 15). It is an encouragement to be open to different ontological perspectives, be they from diverse humans speaking different disciplinary languages or from diverse populations of nonhuman cohabitants.

Whilst methods and intentions vary and have evolved as my understanding of the organism has grown, what lies at the core of all my practices and processes is a fundamental curiosity about what drives the behaviour of this fascinating organism; a desire to share that curiosity and discovery with others; and a will to bring others into the process of enquiry, not as passive participants, but as active agents. I may amplify inherent behaviours which reveal traits and abilities; I may set the frame through which I invite people to ponder, and I may create the stimulus by which I ask people to engage. However, creating the conditions is far from controlling the results.

I have spent considerable time, energy and effort over the years getting to know this curious organism, to understand how it works, and to develop methods for working with its inherent mechanisms. I have fostered collaborative relationships with scientists, designers, choreographers, programmers, and musicians, travelled the world talking about what a wondrous organism it is and persuaded groups of unsuspecting individuals to let go of their humanness and attempt to ‘be’ slime mould for a short while. And in all this time, I realise all too well that the subject of my close attention remains utterly ambivalent to the human curiosity it has unknowingly inspired.

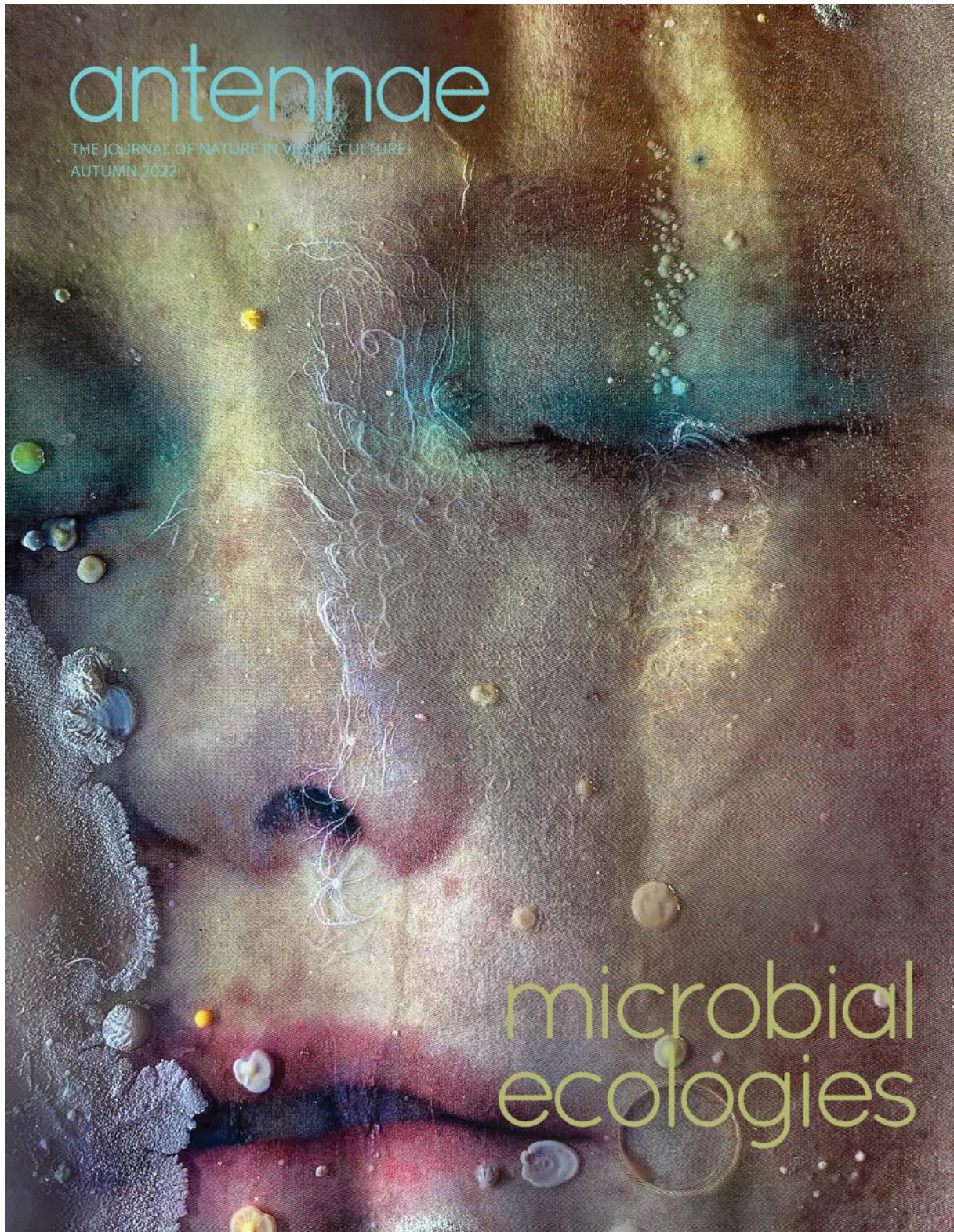
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B.3.4. The Physarum Experiments
Antennae: The Journal of Nature in Visual Culture
Microbial Ecologies (59), 2022, pp. 223–233.



The physarum experiments

This portfolio presents a body of work created with a classic model organism - the slime mould *Physarum polycephalum*. Within a studio setting, the slime mould is staged within novel environments and its growth trajectories captured as it navigates: calculating routes, making decisions, and responding to encounters. Through the representation of emergent growth trajectories and behavioural responses to given interventions the work aims to 'draw out' fundamental processes of life as a relational exercise. Imaging technologies - specifically macro and time-lapse photography - mediate between spatiotemporal subjectivities, amplifying slime mould behaviour to human scale.

text and images: **Heather Barnett**

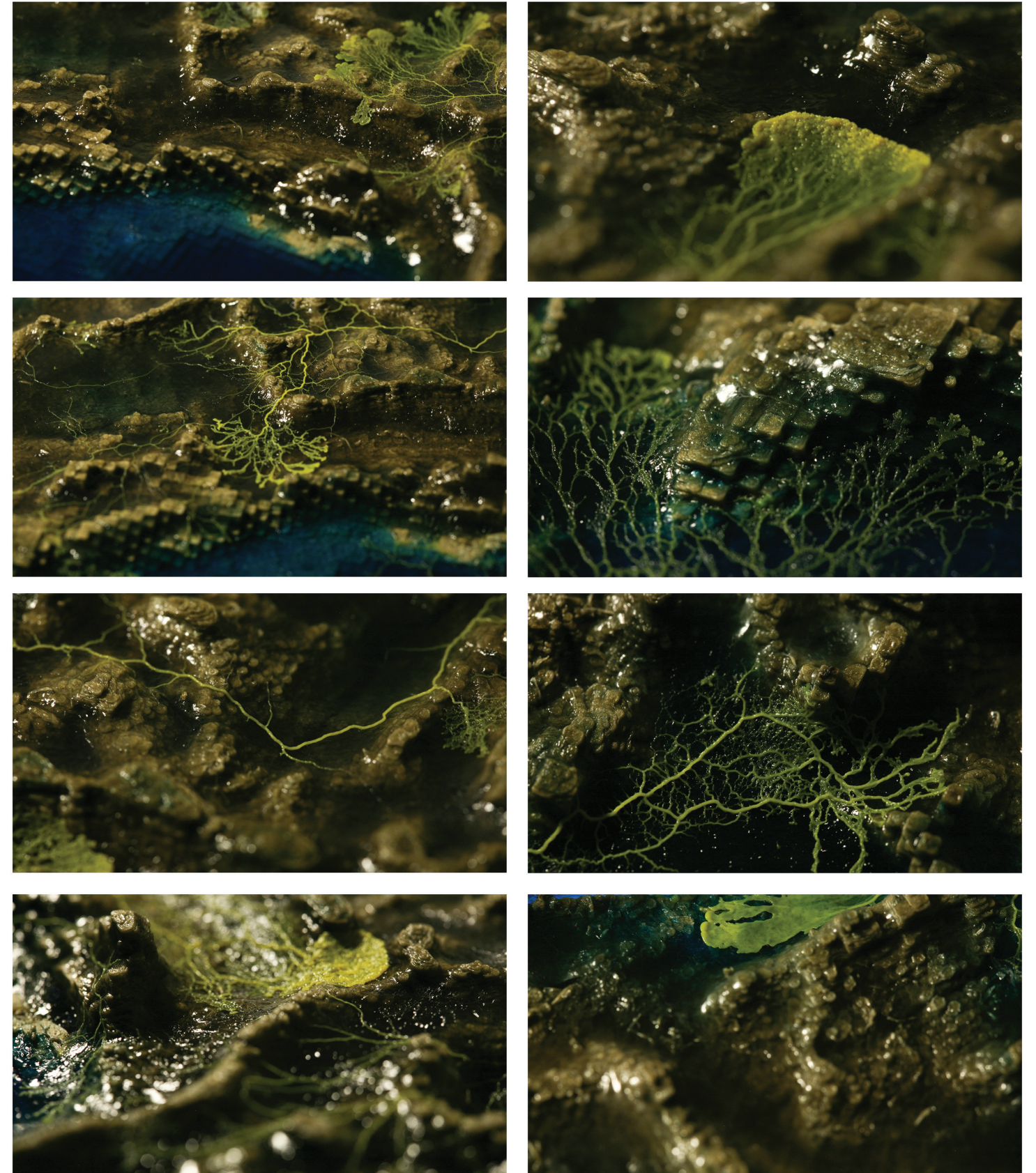
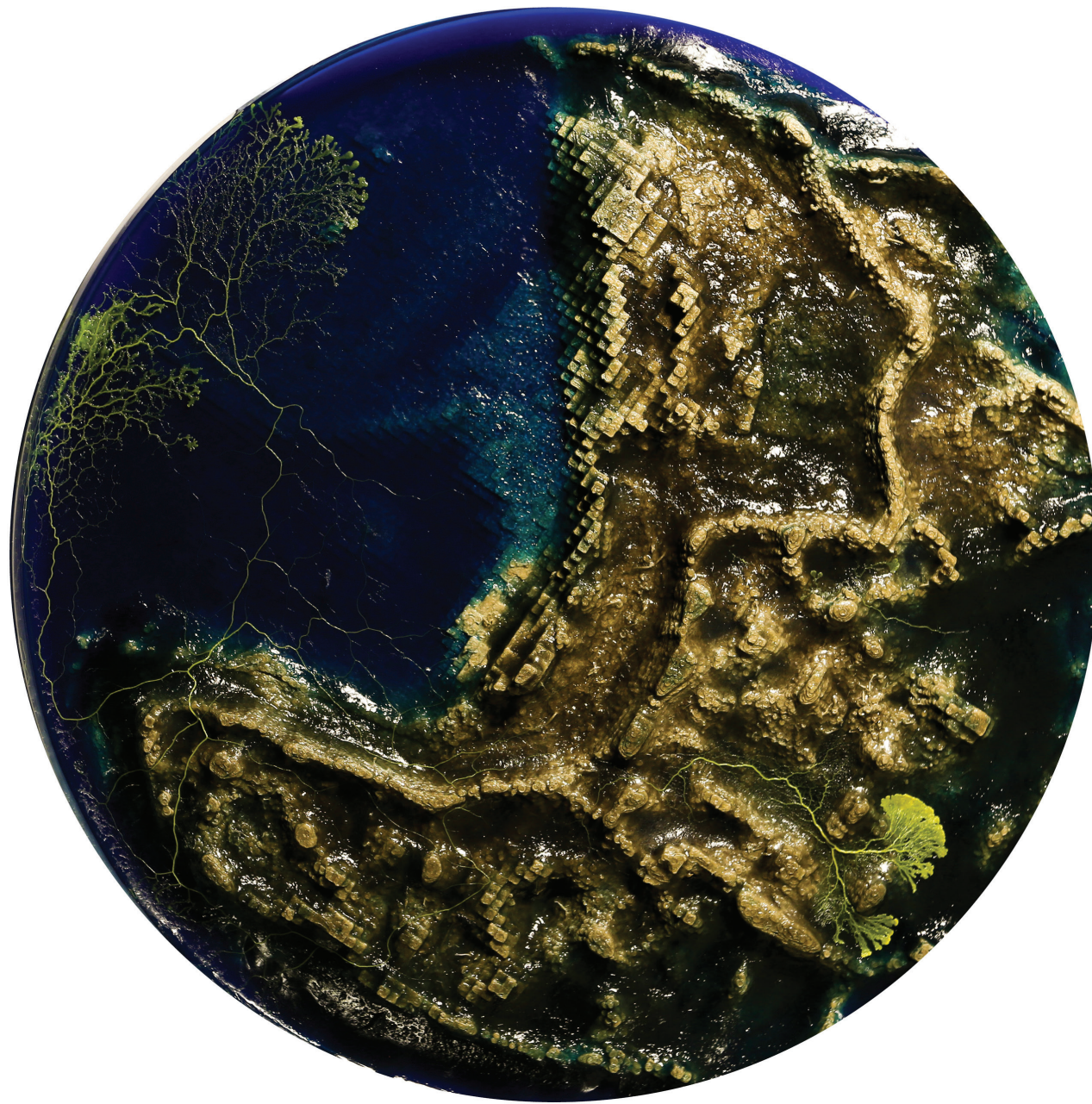
Physarum polycephalum offers us something like the degree zero of sentience and of decision-making. Its mode of thinking doesn't involve concepts, representations, intentional objects, self-awareness, or even an underlying unity of experience; it leaves out most of the things that philosophers have traditionally considered to be necessary or intrinsic to thought. And yet, it feels, and ponders, and decides.¹

Steven Shaviro, *Discognition*, 2016

Since 2009, I have been working with the true slime mould, *Physarum polycephalum*, as material, model, and metaphor, generating speculative artworks reflecting on the relationships between human and nonhuman agents. This 'collaboration' with a single-celled organism has evolved along diverse yet interconnected trajectories, involving the creation of films, installations, encounters, and participatory experiments.² Grouped together under the umbrella of *The Physarum Experiments*, this interdisciplinary artistic research brings human and slime mould intelligence together in a process of interspecies co-enquiry - a sympoietic practice.³

This portfolio centres on films produced working directly with the organism - a process involving the construction of novel environments, within which the slime mould navigates, responding to my interventions. Through a series of invitations and interruptions, utilizing known attractants and repellents, a performative stimulus/response emerges, captured using macro and time-lapse photography. The imaging technologies employed mediate between two different species-specific 'umwelts', defined by naturalist Jacob von Uexküll as the subjective sensorial experience of any living organism within its environment.⁴ Here, time-lapse photography amplifies the biological world of the slime mould, pushing it towards human spatiotemporal scale. The intention of the work is to reveal the underlying mechanisms at play within this fascinating and beautiful organism and, through the aesthetic and technical devices employed, to elicit a relational encounter.

The organism at the heart of this inquiry is a nomadic amoeboid, *Physarum polycephalum*, one of over 900 known species of slime mould to be found creeping around temperate woodlands feasting on rotting vegetation. Comprising thousands, often millions, of individual nuclei, the slime mould operates as a collective entity, highly coordinated with a demonstrable 'primitive intelligence'.⁵ Without any central nervous system and without a brain, it has many noted achievements, including high-level network optimization,⁶ spatial and temporal memory,⁷ and the ability to learn from its environment and to pass that learning



Heather Barnett

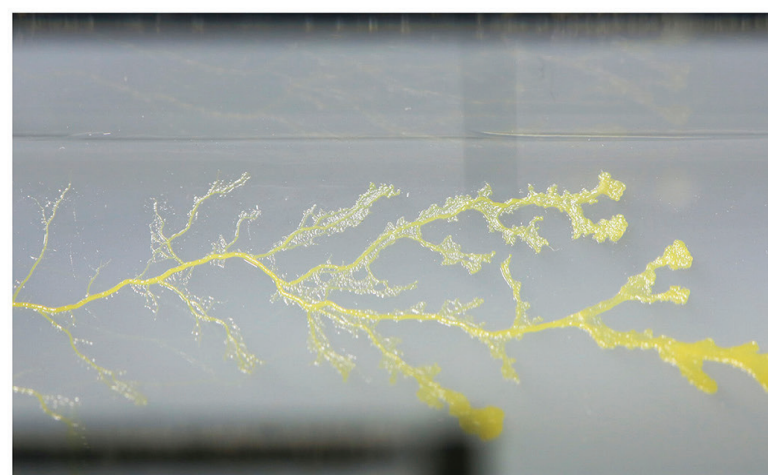
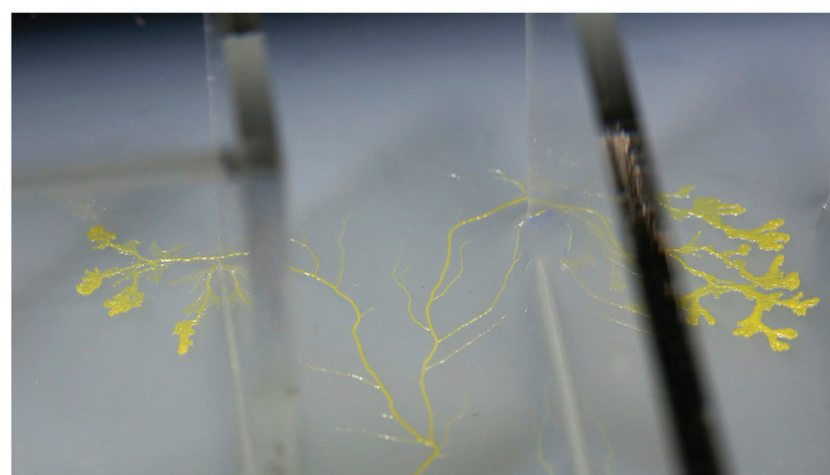
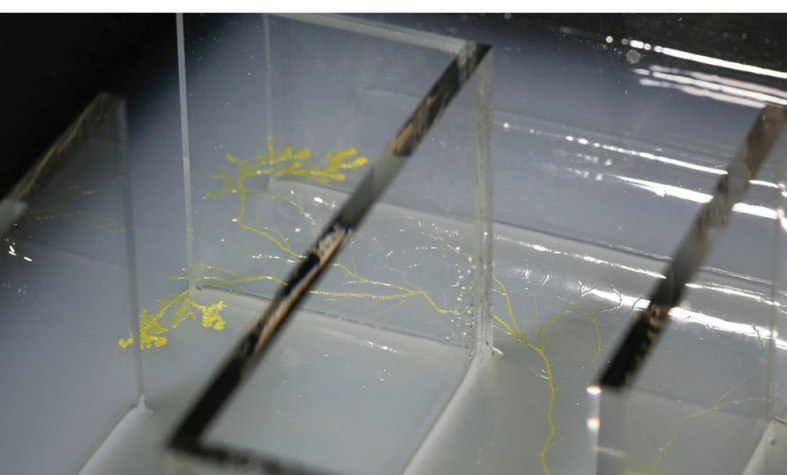
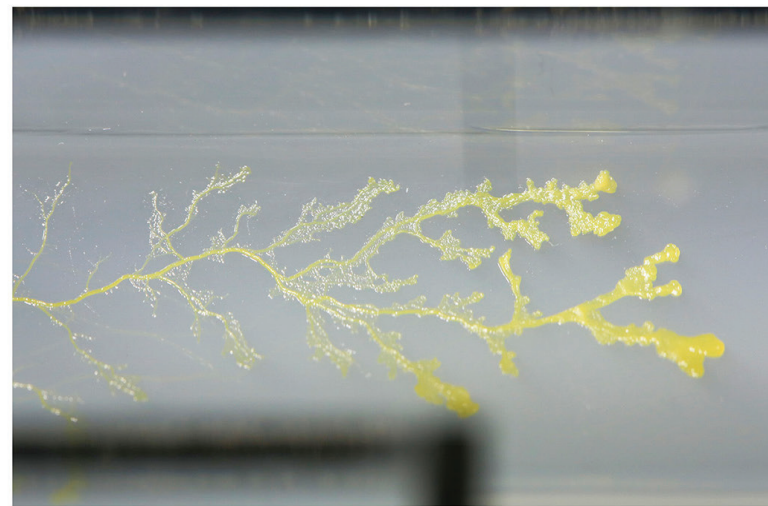
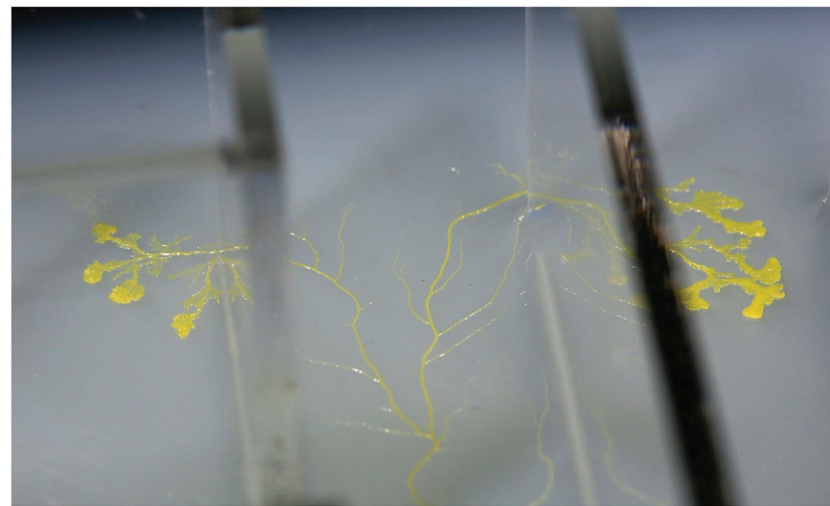
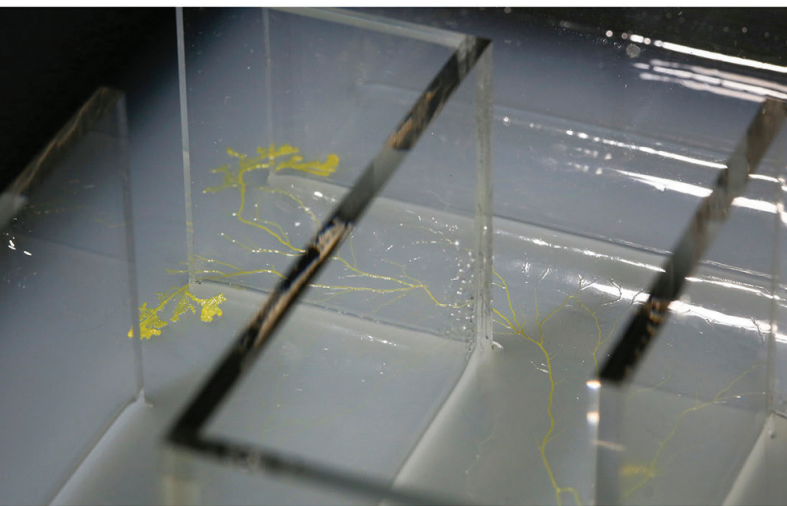
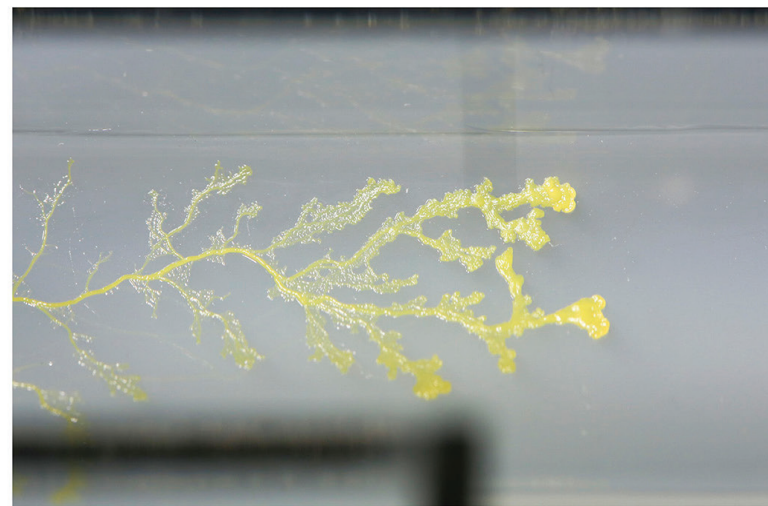
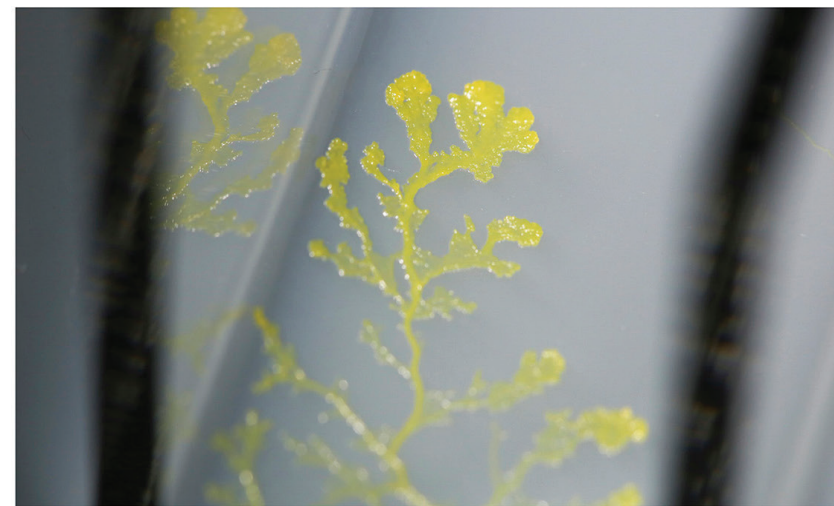
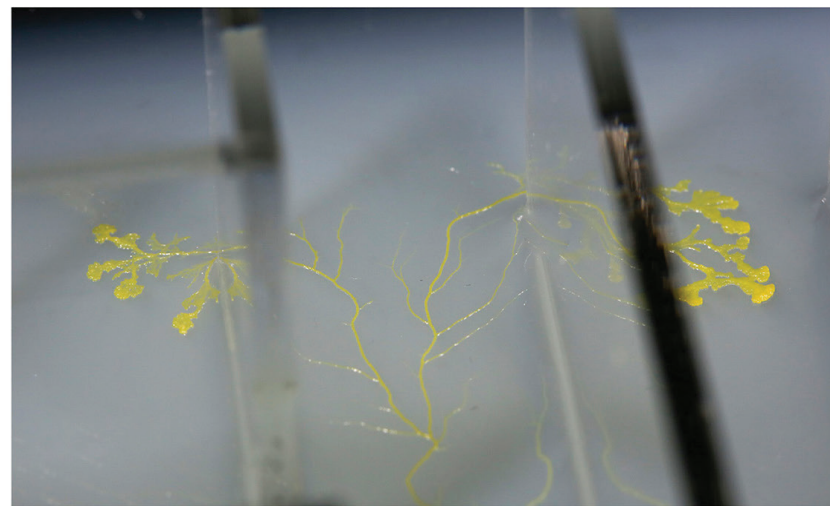
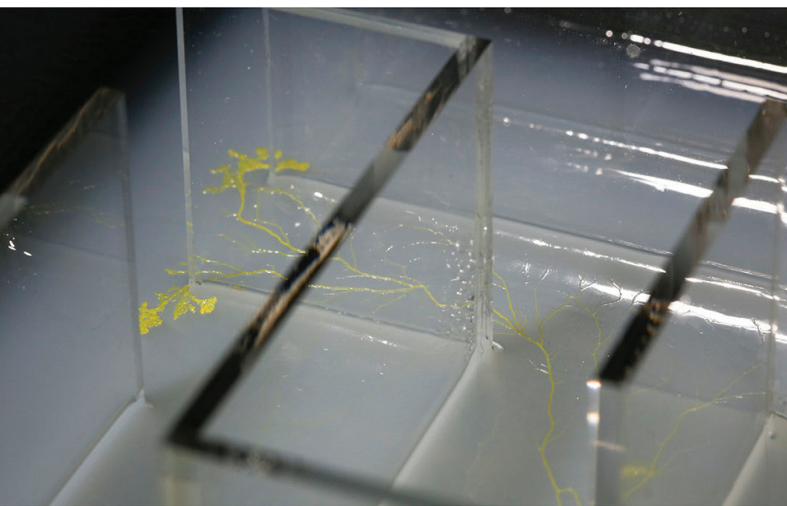
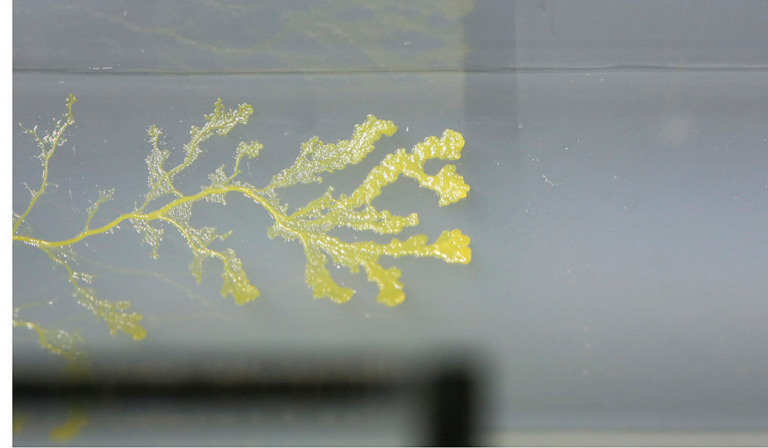
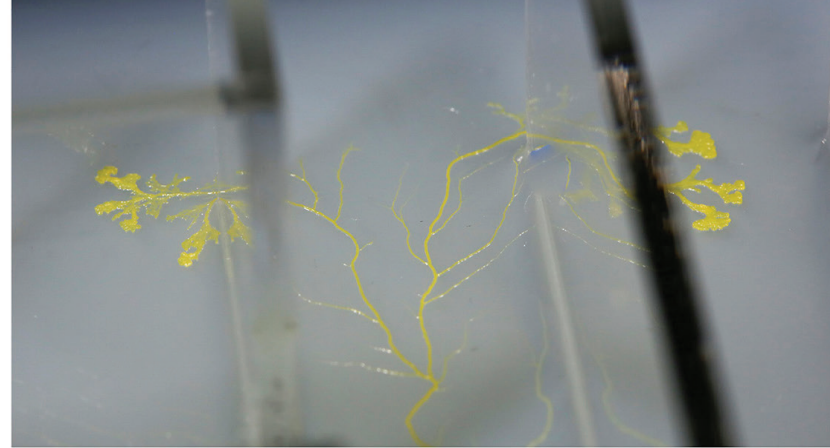
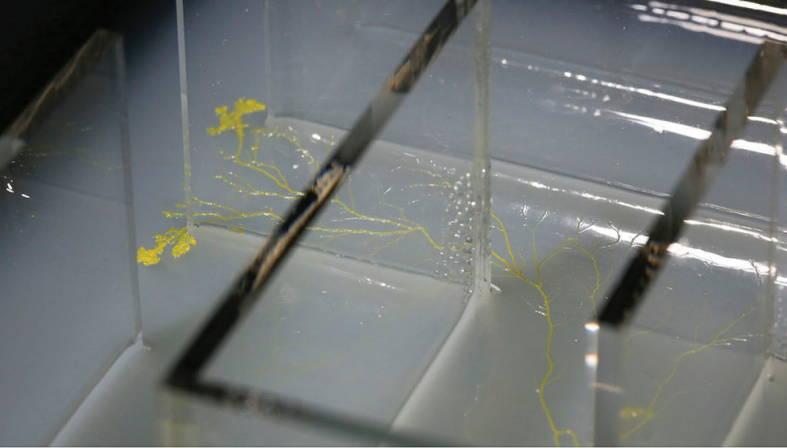
Resilient Topographies #1: the peninsula of Paljassaare

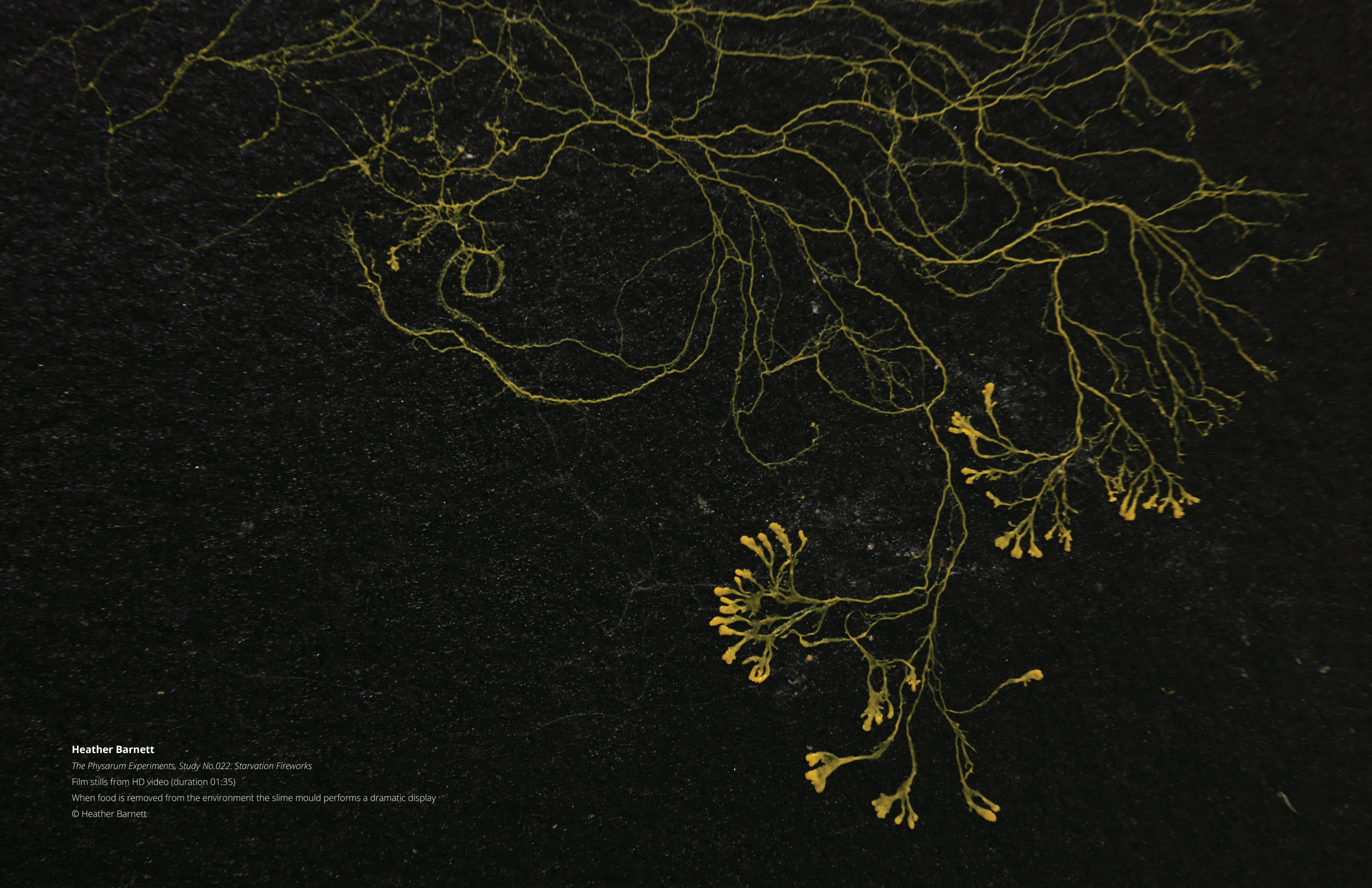
Film stills from HD video

Made in collaboration with ecoLogicStudio for BioTallinn, Tallinn ArchetecturaL Bienalle 2017 © Heather Barnett

Pages 226-227: Film stills from HD video © Heather Barnett

The slime mould navigates a scaled up replica of the maze used in the experiment led by Toshiyuki Nakagaki which demonstrated 'primitive intelligence'





Heather Barnett

The Physarum Experiments, Study No.022: Starvation Fireworks

Film stills from HD video (duration 01:35)

When food is removed from the environment the slime mould performs a dramatic display

© Heather Barnett



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The Physarum Experiments, Study No.026: Intraspecies Fusion

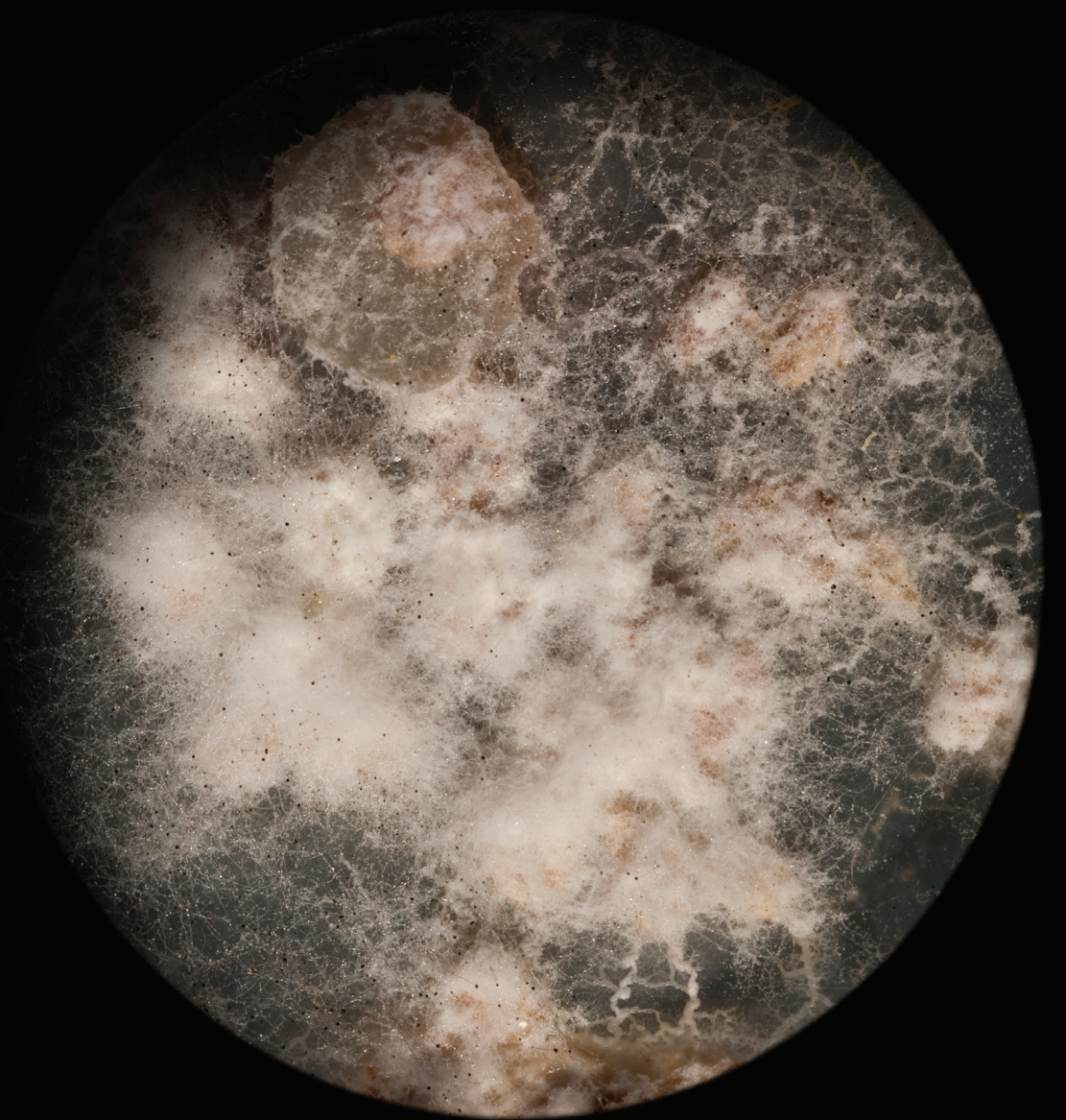
Film stills from HD video (duration 02:47)

Two genetically identical slime moulds meet and fuse, exchanging information and experience © Heather Barnett

onto other slime moulds.⁸ It is therefore little surprise that, outside of its natural habitat, the slime mould has become a valuable model organism, serving diverse fields of enquiry: from biophysics to computer science, from urban planning to philosophy, and from material science to music and art.⁹ In laboratories and studios across the globe researchers are asking myriad questions about the slime mould, seeking to better understand how such a simple organism can achieve such complex tasks.

The slime mould navigates its world through a process of chemical sensing. As the organism roams it interprets the signals it discerns, homing in on food sources, avoiding toxic repellents, and recognizing its own extracellular trail left behind in earlier journeys. Signals are distributed through a process of protoplasmic streaming, a rhythmic flow of nutrients and chemical information shuttling back and forth inside a dynamic network of interconnected veins. Its form is that of a shapeshifting 'body without organs', the 'glacial reality where the alluvions, sedimentations, coagulations, foldings, and recoilings that compose an organism—and also a signification and a subject—occur'.¹⁰ It is ever fluid, constantly adapting in response to its encounters. It is an exploratory environmental barometer, highly sensitive to changes in temperature, humidity, and chemical composition.

In the films I create, I aim to connect the conceptual, biological and aesthetic properties of 'slime mouldness' through the staging of the organism and the capturing of its biological actions and reactions through time-lapse photography. Here, time is manipulated outside of the confines of any species-specific 'moment



Heather Barnett

The Physarum Experiments: remnants of a process #3

Archive digital print (16 x 20")

The remnants of experiments, as environmental moulds take over and cover the traces of slime mould journeys

© Heather Barnett 2009



Heather Barnett

The Physarum Experiments: traces of a journey

Archive digital print (20 x 16")

Traces of extracellular slime deposited by the slime mould as it journeys, leaving a map of where it's been © Heather Barnett

sign',¹¹ which Uexküll defines as the subjective passing of time experienced uniquely by an organism, and enters an intermediary space between human and slime mould rhythm and flow. This filmic *staging* brings different elements to the fore: sometimes directly referencing the scientific studies which have demonstrated memory or learning,¹² sometimes revealing the global dynamics of collective decision-making as the organism is exposed to novel situations and environments.¹³ Different species are introduced¹⁴ and genetically identical slime mould kin are re-introduced.¹⁵ Our definitions of intelligence are called into question.

The films do not follow traditional conventions of scientific or natural history filmmaking and they do not present any fixed narrative. By maintaining ambiguity of scale or time, the visual tropes of time-lapse photography allow the organism to stage itself. Through its oscillatory rhythmic flow of protoplasmic streaming, through the constant pushing and pulling of internal forces, the slime mould reveals the 'cognitive' activity of a chemically sensing body, mediated by the interventions of a curious human. My artistic inquiry *with* slime mould is a form of dialogue between empirical, intuitive, and explicit knowledge systems, as a means to *draw out* the inherent characteristics of the organism.¹⁶ To *draw out* is to entice, to lure something out, to tease into being. A process of gradual extraction, *drawing out* is to prolong, to lengthen time, a pulling of threads. In human terms it can mean to induce someone to speak openly, to reveal true feelings. In slime

mould terms it means to amplify processes of life that lie beyond our perceptual grasp and to scale up the organism (literally and metaphorically) to create a relational space between two radically different spatiotemporal worlds.

The slime mould, simultaneously one and many, offers a rich philosophical 'discourse object',¹⁷ inviting us to speculate... on the nature of self and other, on the identity of the individual and the collective and on the fundamental building blocks of intelligence. Through looking *at* and looking *with* other life forms, I suggest that we might shift our ontological assumptions, allowing us to 'observe the mechanisms of thought in something like their primordial form'¹⁸ - a mode of thought that is distributed and dynamic, and highly attuned to ever-changing environmental conditions.

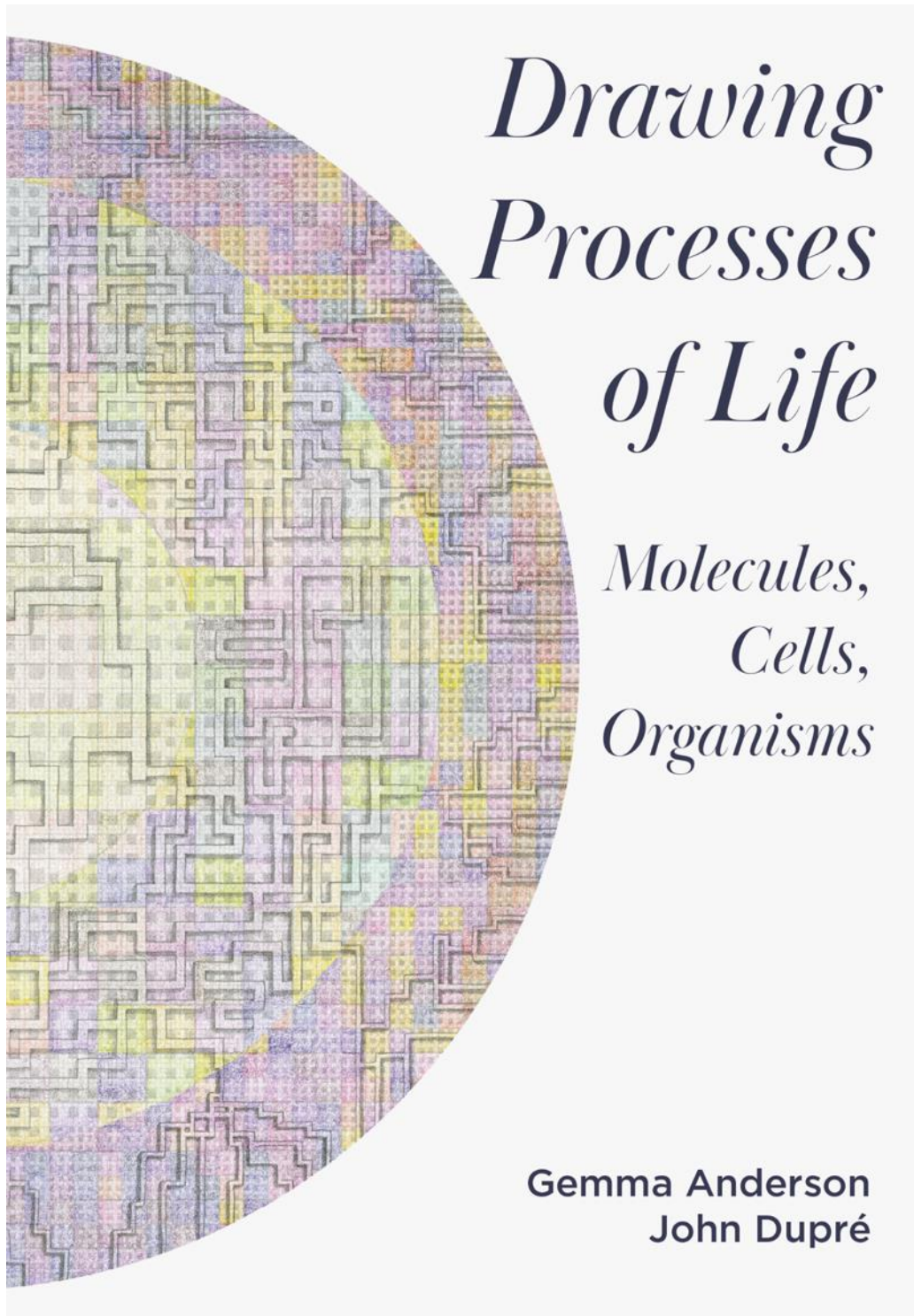
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Heather Barnett is a British artist, researcher, and educator working with natural phenomena and emergent systems. Employing living organisms, imaging technologies, and playful pedagogies, her work explores how we observe, influence, and understand multi-species ecosystems. Recent work centres around nonhuman intelligence, collective behaviour, and experimental systems for co-enquiry, working with humans, ants and slime moulds. Heather is Pathway Leader on the MA Art and Science, and co-director of the Living Systems Lab at Central Saint Martins (University of the Arts London), a Visiting Associate Professor at Tokyo Institute of Technology, and founding member of The Slime Mould Collective.

B.3.5. Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life

in Barnett, H. (2023) 'Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life', in Anderson-Tempini, G. and Dupré, J. (2023) *Drawing Processes of Life*, Intellect Books. pp. 201–226.



7

Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life

Heather Barnett

Introducing the superorganism

[In] trying to understand systems that use relatively simple components to build higher-level intelligence, the slime mould may someday be seen as the equivalent of the finches and tortoises that Darwin observed on the Galápagos Islands.

(Johnson 2001: 12)

As one of around 900 known species of slime mould, *Physarum polycephalum* can usually be found creeping around the ground vegetation of temperate woodland. Comprising thousands, often millions, of individual nuclei, all operating as one single entity, the slime mould is considered a superorganism – a collective organization of individual elements working in highly coordinated ways. Within the superorganism, a dynamic network of interconnected tubules helps distribute nutrients across the cell mass, as well as communicating valuable information about environmental conditions. Among its listed achievements are high-level network optimization (Nakagaki et al. 2000, 2001), spatial and temporal memory (Saigusa et al. 2008), the ability to learn from its environment and to pass that learning onto other slime moulds, even after lying dormant for more than a year (Vogel and Dussutour 2016). It is therefore little surprise that, outside of its natural habitat, the slime mould has become a valuable model organism, serving diverse fields of enquiry, from biophysics to computer science, from urban planning to philosophy and from material science to music and art. In laboratories and studios across the globe, researchers are asking questions

of the slime mould, seeking to better understand how such a simple organism can achieve such complex tasks.

The work under discussion here is a series of time-lapse film studies made between 2009 and 2018, working with *Physarum polycephalum* within a studio environment, introducing the organism to novel environments and capturing its growth trajectories as it navigates: calculating routes, making decisions and responding to encounters (Figure 7.1). The films are part of a larger ongoing artistic inquiry, operating under the umbrella title of *The Physarum Experiments*, which connects slime mould and human ontological sensibilities through

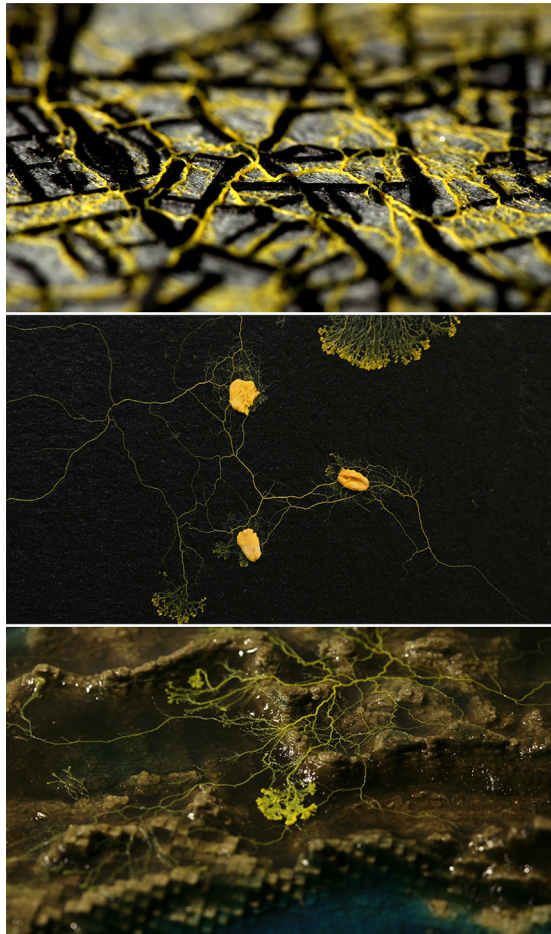


FIGURE 7.1: Still images from the slime mould studies *The Physarum Experiments*. © Heather Barnett.

a range of media and employs hybrid (artistic and scientific) methods. The varied approaches – including the co-creation of experiments, artworks and experiences – seek to draw connections between disparate life forms and create interspecies encounters (Barnett 2019a, 2019b, 2021). My interdisciplinary artistic practice, developed over several decades, involves working directly with living systems, seeking to reveal behaviours which operate beyond human perception. Mediated by imaging technologies, such as microscopy (spatial magnification) or time-lapse photography (temporal magnification), technological intervention aids in a relational exercise, permitting access to other processes of life.

Subjectivities of time

Whatever the relations between a subject and the objects in his environment, they always take effect outside the subject, and that is where we must look for the perceptual cues.

(Uexküll 1934: 327)

As with all organisms, the slime mould operates in the world according to its unique sensory characteristics and physiological capabilities. Its subjective realities are predicated on its species-specific relationship with its surroundings, which operate distinctly but in concert with a multitude of interrelated subjectivities. In his seminal 1934 essay, *A Stroll through the Worlds of Animals and Men: A Picture Book of Invisible Worlds*, naturalist Jacob von Uexküll identifies all creatures as ‘subjects’, not ‘machines’, operating through a complex and highly individualized interrelation of perceptions and actions. By moving away from mechanistic ontological interpretations, ‘We thus unlock the gates that lead to other realms, for all that a subject perceives becomes his perceptual world and all that he does, his effector world. Perceptual and effector worlds together form a closed unit, the Umwelt’ (Uexküll 1934: 320).

An organism’s Umwelt, literally meaning ‘surrounding world’, is based on its body size, its sensory processes and its metabolism – consider the olfactory realm of the dog, the haptic exploration of the octopus or the pheromone landscape of the ant colony. According to Uexküll, the key factors in how an Umwelt operates for any individual organism relate, not only to their inherent biochemical, physiological and cognitive processes but to the spatial configuration of their body plan in relation to their environment, how time behaves in the organism’s world and how individual moments are experienced within the body.

Time as a succession of moments varies from one Umwelt to another, according to the number of moments experienced by different subjects within the same span of

time. A moment is the smallest indivisible time vessel, for it is the expression of an indivisible elementary sensation, the so-called *moment* sign.

(Uexküll 1934: 340)

Arguing against any unified definitions of lived experience, he calculates that humans operate at a ‘moment time’ of one-eighteenth of a second, drawing on empirical studies demonstrating that the human ear hears eighteen air vibrations in one second as a single sound or feels eighteen taps per second on the skin as continuous pressure. This he compares to equivalent studies indicating a ‘moment time’ of a quarter of a second for snails and one-thirtieth for fish, based on similar observational experiments (Uexküll 1934: 341). Based on my own empirical understanding of the slime mould, I would calculate its ‘moment time’ as one beat per 90 seconds, in line with its rate of protoplasmic streaming (Barnett 2013b), the rhythmic pulse of growth that directs all motion of the organism (Figure 7.2).

What is of interest in my own visual enquiry is the relationship between the lived experience of time and the representation of time through technological mediation, specifically, how the rhythms of life can be amplified from slime mould to human spatio-temporal scale. As an image-maker working with differing organisms’ moment times, the question is how to translate those shifting scales of perception into moving image – how to capture, render and represent the rhythm of life and growth in motion. If humans operate at around one-eighteenth of a second frequency, it follows that they perceive movement at the same base rate, so any moving image screened at eighteen frames per second (fps) or above will be perceived by humans as natural motion. Commonly, film and video are screened at 24 fps and more recently at 30 or 60 fps or higher as technological developments allow for better resolution and faster frame rates. The logic, therefore, would follow, that films made for an audience of snails would be screened at four fps to appear convincingly ‘real’ to a snail audience and for slime moulds at around one fps or slower.

Despite the obvious nonsensical limitations of making moving-image entertainment for organisms that operate in an olfactory or chemosensory – and non-visual – world, speculative enquiry has its value. Supporting his investigations into the relative subjectivities of organisms, Uexküll utilized imaginative visualization as a form of speculation. His studies were illustrated with drawings and altered photographs depicting how a given organism ‘sees’ the world; for example, a village street scene as seen by a human, a fly or a mollusc (Uexküll 1934: 335). Of course, the accuracy of any such representation is questionable. Even if we have a physiological understanding of how a bird visually perceives the world based on its optical and neurological make-up, we cannot know with any confidence how it understands what it sees, spatially or conceptually. What Uexküll offers us in his representations,

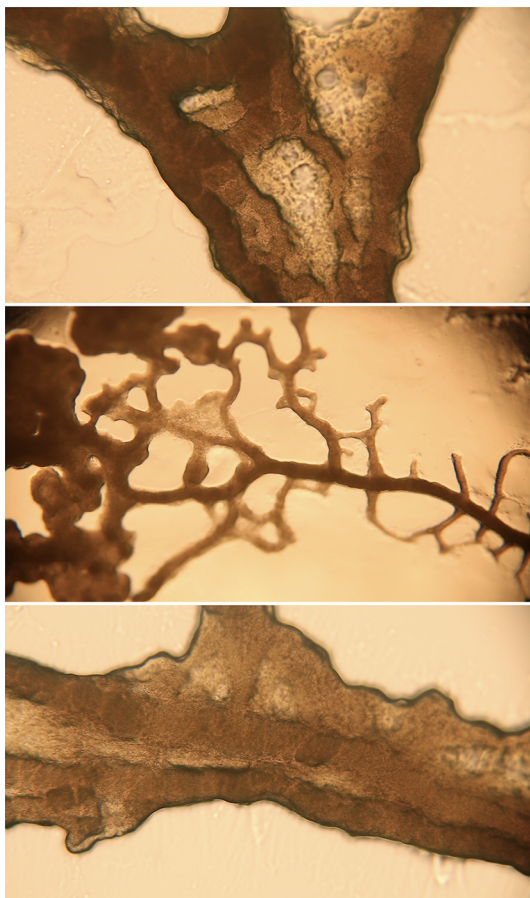


FIGURE 7.2: Still images from *The Physarum Experiments, Study No.020: Streaming*, showing the flow of nutrients and chemical information within the network of dynamic veins (2013). © Heather Barnett.

and what I offer in my film studies, is a visual ‘potentiality of experience’ (Elkins: 96) inviting the viewer into another realm of sensory and temporal perception.

In my investigations, I use cameras and computers to transcend the temporal worlds of human and slime mould. I am interested in how we perceive the passing of time in our own world (in mind and body) and the relative subjectivities of time through human/slime mould speculation. Through the representation of growth trajectories and behavioural responses to given interventions, I aim to ‘draw out’ fundamental processes of life and use technological mediation – specifically macro and time-lapse photography – to create a relational encounter.

Perceptual processes

We must recognize that Nature itself is always in movement, in process, and under construction.

(Shaviro 2016: 216)

The slime mould's Umwelt is one of biochemical sensing, navigating its world through chemotaxis. As the organism roams, it is constantly interpreting the chemical signals it discerns, homing in on food sources, avoiding toxic repellents and recognizing its own chemical trail left behind in earlier journeys. Signals are distributed through the body of the organism through a process of protoplasmic streaming, a rhythmic flow of nutrients and chemical information pulsing inside a dynamic network of interconnected veins. Its physiological properties are driven by protein dynamics, actin and myosin contracting and releasing – the same proteins activating human muscular motion – enabling it to pulse in multiple directions simultaneously (Nakamura and Kohama 1999). The supercell is held together by a mucus membrane containing a multitude of individual nuclei shuttling around within. Its body is a shape-shifting network, always fluid, ever-changing in response to its surrounding world. It is a nomadic environmental barometer, highly sensitive to changes in temperature, humidity and chemical composition. It can also detect changing pH in its environment, which manifests in a morphological colour change from bright yellow to darker orange (Seifriz and Zetzmann 1935).

These dynamic processes give rise to particular growth patterns: branching out whilst foraging (to maximize coverage of territory) and forming networks once nodes have been established (to strengthen connections and facilitate the transfer of information). Branching is a fundamental strategy within myriad biological organisms and physical phenomena, from the bifurcation of river deltas, lightning strikes, tree roots and branches, to mycelial networks and in our own bodily systems including blood vessel networks and the cross channelling of neural pathways. Branching facilitates 'the transmission and parsing of information, no less than the transfer and dissipation of energy' and, according to philosopher Stephen Shaviro, 'is an essential process of Nature' (2016: 220). Taking advantage of the affordances offered by its physiology and the sensory ecology of its Umwelt, '*Physarum polycephalum* continually prods, pokes, and provokes its environment. It navigates and searches, oozing and flowing and extending itself through its surroundings' (Shaviro 2016: 213). As such, the slime mould is an oscillatory information processing and distribution system, operating within a constant feedback loop of communication 'from its encounters with objects, fields, and energy flows all around it' (Shaviro 2016: 214). And it is these same flows which I aim to harness in my own interventions with slime mould processes.

For Shaviro, ‘information processing mediates between perception and action’ (2016: 220) and forms the basis of fundamental sentience within the natural world. He does not suggest that organisms such as trees or bacteria are conscious, but he does argue that ‘they are demonstrably sentient, as they process information and respond to it in ways that are not stereotypically determined in advance’ (Shaviro 2016: 221). This unconscious information processing, not entirely dissimilar to the extensive subconscious neural activity within our own brains, gives rise to unpredictable and nuanced responses to changing environmental conditions. It is far from mechanistic and allows the organism to recognize the significance of signals and make decisions about what to do next. The many admirable attributes of slime mould are an emergent property of the multitude of interactions within the superorganism and between its body and its environment – a dialogue between a many-headed organism and its world.

In the films I create, I aim to bring together the conceptual, biological and aesthetic properties of ‘slime mouldness’ through the staging of the organism within constructed environments and the capturing of its biological actions and reactions through time-lapse photography. Here, time is manipulated outside of the confines of any species-specific ‘moment’ time and enters an intermediary space between human and slime mould rhythm and flow, drawing the two realms together. The ‘moment’ of time-lapse photography is one which can encompass these relative subjectivities of time. Time itself becomes a medium by which to translate processes of one life form to be better understood by another.

Playing with time

The ‘revealing “eye”’ of the microscope and the ‘analytical “brain”’ of the camera were described as active observers: by portraying the aliveness of the world, technology itself came to life.

(Field et al. 1942: 52)

There are certain practical challenges to overcome in photographing slime mould, an organism that does not like light and that moves very slowly. Too much light alters the slime mould’s physical state, forcing it to switch from a continuous growing plasmodium into a fruiting body containing spores. Growth-wise, its top speed is around one centimetre an hour, depending on a number of interconnected variables such as humidity, temperature and relative states of hunger – for example, it slows down when too cold or too dry and increases fluctuations when it finds food. These growth characteristics are imperceptible to human observation in ‘real time’. Therefore, imaging technologies – in particular time-lapse

photography – are employed as a means of amplification and translation. This mediation involves the capture of individual still images at regular intervals. Shooting over hours, sometimes days, the numerous stills are then composited into a continuous moving image, recombining instances at a fast enough frame rate to represent perceivable motion. Humans perceive movement convincingly at 24 frames per second (or as stated previously, according to Uexküll’s experiments, at a minimum of eighteen). The fast succession of images creates the illusion of natural motion so that the viewer is perceptually convinced of its authenticity.

Capturing the processes of life in motion has a long history, dating back to early twentieth-century cinematographic innovators such as Percy Smith, who pioneered time-lapse and microphotography. His inventive films presented the behaviours of organisms as never seen before, producing an eclectic filmography throughout his career. As part of a team working for British Instructional Films after the First World War, he contributed greatly to a series of natural history films, *Secrets of Nature* (1922–34), which depicted vernacular views of plants, animals, birds and insects (Long 2020). As part of this series, he captured the slime mould in *Magic Myxies* (Smith and Field 1931), a ten-minute black and white film which reveals the curious characteristics of slime mould, here defined as both animal and vegetable. Despite this taxonomic inaccuracy (slime moulds have also been classified as fungi and are now settled within the kingdom of the amoeba) and the amusing anthropomorphism at play in the typically 1930s BBC narration, the film depicts the full complexity of the organism’s life cycle and physiology, including spore dispersal, plasmodial migration and fusion. The granular detail of protoplasmic streaming is also depicted and described, as a channel pulsing forward and backward, ‘this ebbing and flowing causes the Myxie to advance like the sea, in waves’ (Smith and Field: 1931 04:10).

The influence of filmmakers such as Smith, and the form of biological representation they pioneered, can be seen in the development of natural history filming over the last century. The BBC Natural History Unit has produced incredible footage of slime moulds growing in their (seemingly) natural habitat, traversing logs and consuming mushrooms (*Autumn* 2013). More recently, films such as *The Creeping Garden* (2014), a feature-length documentary, have placed the slime mould – and the people who work with them – centre stage in innovative ways. And in 2016, *Magic Myxies* was re-visited by musician Stuart Staples, who re-cut Smith’s microscopic footage accompanied by a ‘sometimes soothing and often sinister’ (Barkham 2016: n.pag) instrumental score. *Minute Bodies: The Intimate World of F. Percy Smith* is an ‘interpretative edit’ which creates ‘a hypnotic, alien yet familiar dreamscape that connects us to the sense of wonder Smith must have felt as he peered through his own lenses and seen these micro-worlds for the first time’ (Brown 2016: n.pag.).

Questions of representation fall into technical, communicative and ethical dimensions. The perceived status of the organism may be affected by the choice of camera angle, scale and viewpoint, how it is framed and with what contextual information in relation to surrounding circumstance. These in-camera decisions, along with other factors relating to interval time and editing decisions, combine to form a representational assemblage which portrays the processes of life. There is also a question of intervention, i.e. to what extent the filmmaker interferes with the biological processes in order to maximize the drama of natural events. Most contemporary natural history filmmaking follows a strict line of non-intervention, the film-makers role being merely to observe. In contrast, Smith's early films involved the glueing of a fly onto a tiny chair so that it could juggle a ball with its legs. In my own time-lapse studies, I take the organism out of its natural habitat and into constructed environments, but with some consideration for the wellbeing of the organism. Knowledge of environmental preferences and biochemical responses, coupled with time subjectivities, enable me to create the conditions for the slime mould to reveal itself and form its own biosemiotic language.

Learning from – and with – the organism

Many of the processes we might consider fundamental features of the brain, such as sensory integration, decision-making and now, learning, have all been displayed in these non-neural organisms. The survival of slime moulds depends on their ability to respond and adapt to changing environmental conditions.

(Boisseau et al. 2016: 6)

My own early time-lapse studies were an ad hoc exploration of what was happening in slime mould time. Initial experiments introduced the organism to various food sources including plants and desiccated insects, as well as known culinary favourites such as oat flakes. I grew it on a range of substrates including coloured agar gel, wet felt fabric and velvet covered in agar – in fact, any material that would hold moisture and provide a suitably humid environment (Figure 7.3). Through these early studies, I observed an array of intriguing behaviours and growth formations and whilst I could predict certain responses, the slime mould would not always conform to my expectations. It was clearly following its own behavioural logic, but I could influence its trajectories to some extent through the placing of attractants or repellents or by altering environmental conditions.

My understanding of the organisms' preferences and their underlying physiological mechanisms grew through a combination of empirical study, coupled with



FIGURE 7.3: Early studies experimenting with different food sources and substrates. © Heather Barnett.

explicit knowledge gleaned from the abundant scientific papers – there are over 67,000 published academic papers on slime mould cited on Google Scholar. For example, in *Study No. 011: Observing growth over 136 hours* (Barnett 2009), having fed on a pile of oat flakes the slime mould set off exploring, two ‘heads’ setting route simultaneously. As the two branches extended across the terrain, they gradually grew towards each other and, prior to the meeting, the entire organism paused in its tracks and shifted its direction of flow in search of novel foraging territory. Before the point of physical contact, the slime mould recognized that it was already there and changed its course of direction (Figure 7.4).

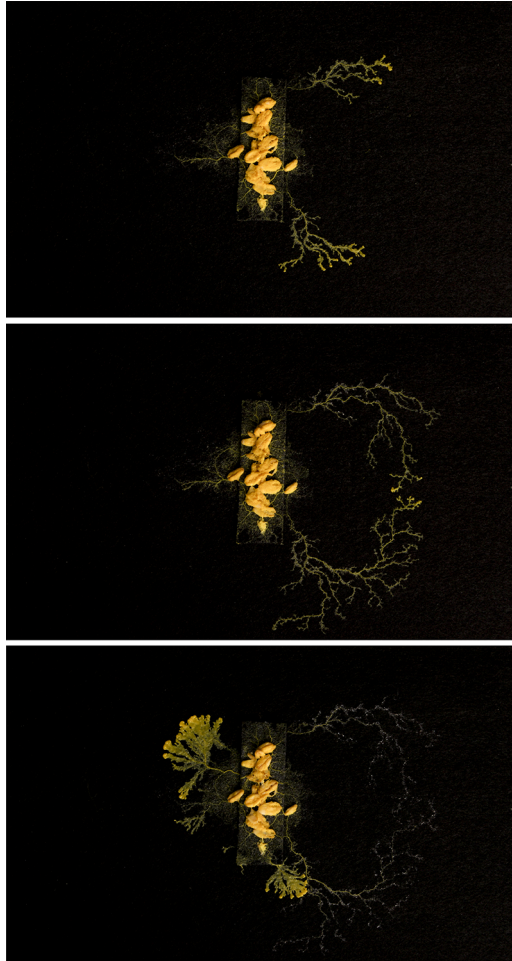


FIGURE 7.4: Still images from *The Physarum Experiments, Study No. 011: Observing Growth over 136 hours* (2009). From top-down; growth trajectories; point of recognition; change of direction. © Heather Barnett.

This form of self-awareness, known as allorecognition, enables the organism to identify ‘self’ from ‘non-self’ in its environment. In slime mould, this function is facilitated by an extracellular sheath extending from the membrane of the supercell, which enables it to initiate fusion or to avoid repellents (Masui et al. 2018). This ‘self-extension model’ identifies chemical information transmission through direct physical contact and through airborne molecules enabling the organism to transmit information about itself into the world (Masui et al. 2018: 7). In *Study No. 011*, non-contact recognition of self was demonstrated as the two slime mould

‘branches’ converged on one point, allowing the organism to alter its flow of energy and change direction of travel.

Allorecognition can also be seen at play in later time-lapse studies, in the fusion of genetically identical slime mould cells and in the avoidance strategies of two species of slime mould in an enforced encounter. This chemical recognition of self and other when seen through the amplification of time-lapse photography suggests seeming intention in the organism’s decisions and trajectories. This function plays a significant role in its navigational abilities, as it deposits a trail of extracellular slime indicating where it has been and helping it to make decisions about where to go next – a form of externalized spatial memory, which is also affected by the complexity of the environment (Smith-Ferguson 2017) (Figure 7.5).

In addition to spatial memory, the slime mould possesses a form of temporal memory, demonstrated in a scientific study where the slime mould was exposed to cold dry air at regular intervals. The change in atmospheric conditions was not conducive to the slime mould and, as a result, it slowed down its growth in response to the unfavourable conditions (Saigusa et al. 2008). Once a pattern was established, the slime mould slowed down each time it felt the cold air, the researchers did not change the atmospheric conditions at the allotted time, yet the slime mould slowed down in anticipation of the event. Somehow the slime mould, without any sensory organs or central nervous system, was able to hold time-sensitive information about an expected event and adapt its behaviour in anticipation of its occurrence. The results of this experiment set out further questions about how the organism was capable of remembering, learning from and predicting events.

The research into slime moulds is vast and multi-disciplinary. From the fields of biochemistry, biophysics and computer science to urban planning, architecture, management theory and philosophy, research relates to questions of information distribution, adaptive networks, self-organization and collective coordination. Much of the recent work, undertaken over the past twenty years – both within and beyond scientific fields of study – was inspired by a seminal paper whereby the slime mould was tasked with solving a specific navigational problem of a maze. In 2000, a team of scientists at Hokkaido University in Japan designed an experiment to test the networking efficiency of *Physarum polycephalum* (Nakagaki 2001). They constructed a maze and filled it with sections of the plasmodium, which spread and conjoined into a single mass cell. Food was then added at two points in the maze and the organism was observed as it contracted to form a thick tubular network connecting the two nutrient sources. The organism retreated from empty areas of the maze, gradually rationalizing its form to a single dominant connective thread, taking the shortest and most efficient pathway. The



FIGURE 7.5: Extracellular slime trail forming an externalized spatial memory, helping the slime mould to navigate its environment. © Heather Barnett.

experiment, led by Toshiyuki Nakagaki, concluded that ‘this remarkable process of cellular computation implies that cellular materials can show a primitive intelligence’ (Nakagaki 2000: 470), thereby sparking much-heated debate amongst the scientific community about how ‘intelligence’ is attributed and how it is defined in organisms without a brain. Whilst there is still much to establish about how the slime mould performs beyond the sum of its parts, it is widely held within the scientific community that the source of the slime moulds’ myriad capabilities is the frequency of oscillations within the process of protoplasmic streaming, a rhythmic and dynamic force.

Staging the organism

The Body without Organs is that glacial reality where the alluvions, sedimentations, coagulations, foldings and recoilings that compose an organism – and also a signification and a subject – occur.

(Deleuze and Guattari 1987: 159)

Engaging with the scientific literature helped underpin and inform my empirical learning and corroborated what I was observing directly from the organism. The scientific methods and research findings also inspired my artistic experiments, albeit in a non-hypothesis-driven way. My motivation was not to replicate the scientific experiments but to use them as a springboard for a more open-ended and exploratory form of enquiry, a staging of the slime mould, creating the conditions whereby the organism could reveal itself through my intervention. For example, my homage to the maze experiment, *Study No. 019 The Maze* (Barnett 2013a), took the form of a large Perspex three-dimensional maze set in a blacked-out chamber (to maintain favourable dark environs). Using the original maze design as a starting point, my replica scaled up and elevated the experimental terrain. In contrast to Nakagaki's experiment, the slime mould in this maze was encouraged to roam freely in search of food (Figure 7.6). I was interested in observing its growth trajectories as it navigated pathways – how it occupied the space – and how it would decide on a given path when presented with a choice – whether one 'head' would dominate or the organism would split into two to optimize potential finds.

In exhibition, when *Study No. 019 The Maze* is screened, it is often accompanied by the sculptural maze containing a live slime mould. This offers the viewer an opportunity to experience the living organism in action though, at a top growth speed of about one centimetre per hour, this requires considerable patience and close nuanced observation. The frustration inherent within this act of viewing becomes part of the exercise, however, to give contrast between the spectacle of the slime mould writ large on-screen, its behaviour accelerated and amplified through time-lapse photography, and the real organism slowly creeping around the maze looking for nourishment. It is an attempt to bring the human viewer a little closer to the slime mould's temporal existence, to create a small perspective shift.

Other environments I have constructed for slime mould exploration include the creation of moistened felt, velvet or paper substrates, 3D-printed terrains poured with coloured agar, petri-dish-scapes cast in agar and the application of various combinations of artistic techniques such as paper embossing, carving, laser-cutting and sculpting. These scenarios invite the slime mould to explore, navigate and encounter within a constructed environment, one that is artificial but made with the organism's needs in mind. The rationale to situate the experiments within

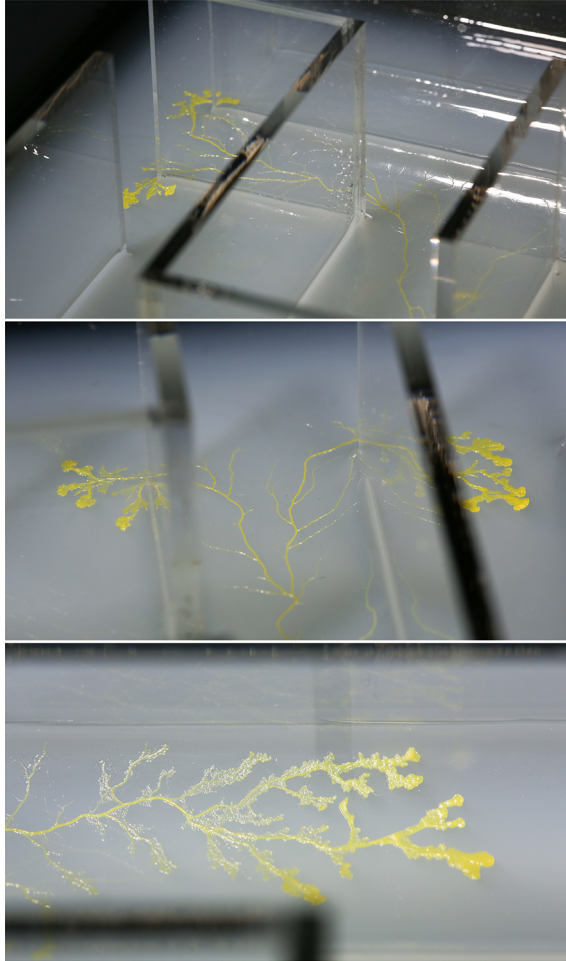


FIGURE 7.6: Film stills from *The Physarum Experiments, Study No. 019: The Maze* (2013). © Heather Barnett.

such a non-natural environment is multifaceted. On the one hand, to shoot in a studio/lab environment offers a degree of control over environmental conditions – I can maintain levels of light, humidity and camera position, which would be difficult to maintain in a natural environment. But it is not purely a pragmatic choice. The environments I construct lack any specific context and are devoid of any indicators of scale. Nor do I publish the time ratios at play within individual films, indicating the interval rate of shooting or the frame rate of playback. It is hoped that, by avoiding any scientific or natural history signifiers in the frame, the resulting ambiguity will draw the viewer in to decipher the structural behaviour

and patterning properties for themselves – to speculate on what they are witnessing. The lack of explicit knowledge presented is intended to elicit a more tacit and experiential engagement with the processes of life at play.

By providing conducive environmental conditions and utilizing known attractants and repellents, the behaviour of the organism and its resulting growth trajectories are influenced by human intervention. Responses to given stimuli can often be predicted but can never be controlled. The slime mould will find all manner of interesting strategies for evasion, access or subterfuge and the results are often surprising. For example, in *Study No. 022* (Barnett 2016a), midway through an exploratory experiment I removed all food from the environment. Knowing that the slime mould was able to detect food from some distance (not solely through direct contact) I was curious as to how it would respond to the sudden change in the availability of resources. The resulting trajectories were flamboyant, the slime mould shooting out dramatically in a wide array of branches, the overall effect resembling a firework display (Figure 7.7).

Here, the relative states of hunger/satiation became part of the experimental setup. If there is too much food in the environment the slime mould will merely sit and digest it, which, depending on the number of oats provided, could take several days. If too hungry, it will not have the energy to ‘perform’ for the experimenter, so balancing this state is a key element to slime mould experimental design. Generally, a well-fed slime mould placed in a novel environment will generate a successful slime mould experiment. With no chemical traces from prior activity to distract it and with lots of energy pulsing around its veiny plasmodial body, an interesting response is likely to occur.

It is not only the environmental conditions that influence what behaviour is represented through time-lapse photography. The space of intervals between each photograph taken significantly affects the spatial representation and what aspects of physiological response are made evident. For example, to demonstrate the pulsing mechanism of protoplasmic streaming, the interval rate should be no more than 60–90 seconds, as that is the time it takes for the direction of flow to shift direction. To view more dynamic global trajectories, a less frequent interval rate should be adopted. For example, the dramatic effect of the starvation fireworks was shot at an interval rate of one frame every three minutes over a period of several days, compared to the maze navigation which was shot at an interval rate of one frame every twenty seconds, over several hours. In the latter, the rhythmic flow of protoplasmic streaming is clearly visible.

In another experiment, *Study No. 024: Interspecies Encounters*, I introduced two species of slime mould into an environment equidistant to a food source (several oats placed in the centre of the dish) (Barnett 2016b). In addition to *Physarum polycephalum*, my regular ‘collaborator’, this experiment also involved a

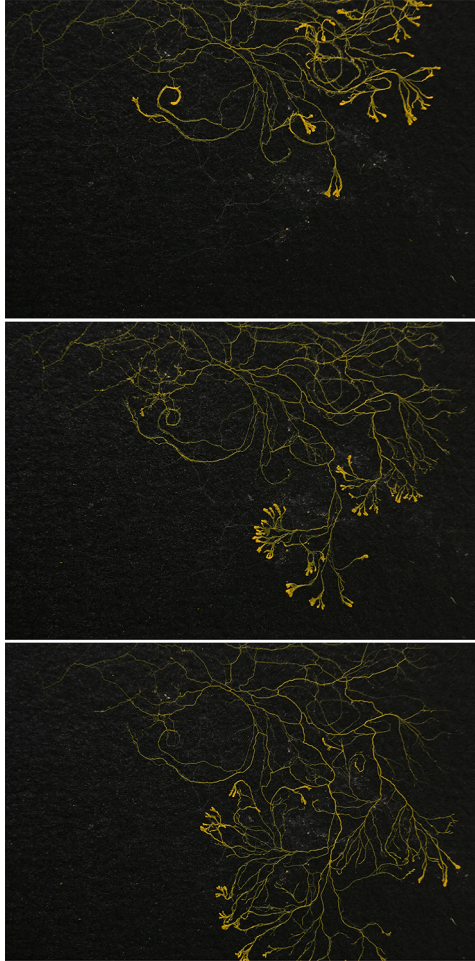


FIGURE 7.7: Film stills from *The Physarum Experiments, Study No. 022: Starvation Fireworks* (2016). © Heather Barnett.

Danish species of plasmodial slime mould, *Badhamia*. Whilst the two organisms share general physiological behaviours, the characteristics revealed here are highly individualized: *Physarum polycephalum* bifurcating long distributed tentacles, whilst *Badhamia* forming a dominant driving force pulsing towards the other slime mould.

As the time-lapse evolves, the *Badhamia* pushes forward, past the oats (not *Badhamia*'s favourite food it turns out), intimidating the *Physarum polycephalum* into retreat, forcing it to change tack and forage in other directions – a battle clearly won. However, on closer inspection, it is possible to detect a small offshoot

of *Physarum polycephalum* which has taken refuge behind an oat as the *Badhamia* wall of attack passes by (Figure 7.8). A satellite slime mould had broken off from the retreating main body and taken evasive action, avoiding detection by the other more aggressive organism.

What I describe here is akin to interspecies warfare strategies and suggests a pre-emptive form of action, weighing up the relative attraction of food vs. the hostility of the other organism. This might seem like an anthropomorphic projection of human sensibilities and cognitive reasoning onto a single-celled creature,

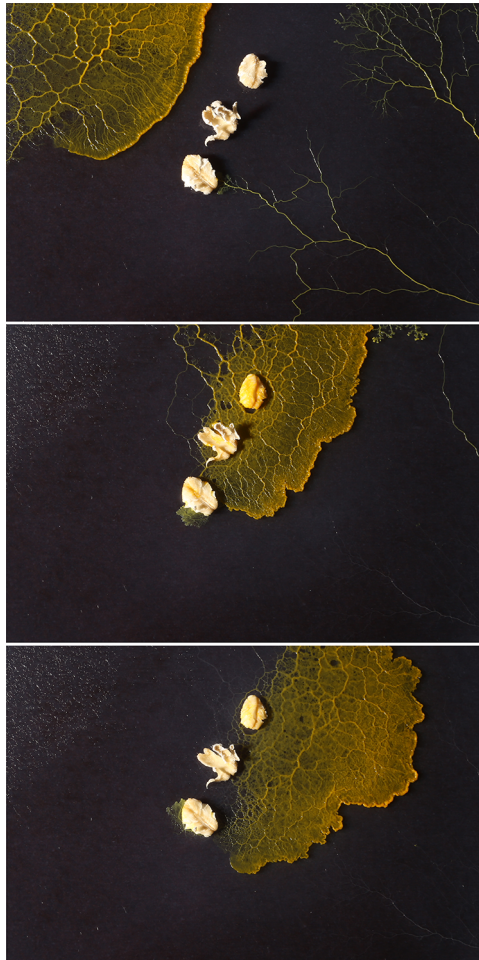


FIGURE 7.8: Film stills from *The Physarum Experiments, Study No. 024: Interspecies Encounter* (2016). © Heather Barnett.

but this attribution is supported by the scientific literature. There are numerous papers on decision-making which analyze variable cost/benefit trade-offs (Beekman and Latty 2011, 2015; Reid et al. 2013, 2016) and, despite the caveat of anthropomorphization, it is hard to dispute that *Physarum polycephalum* took evasive action in direct response to the other organism's presence, position and direction of movement. Its response is a combination of multiple minute calculations assessing what was happening at that moment and what might happen next.

The final example to include here, *Study No. 026: Intraspecies Fusion*, introduced two genetically identical slime moulds in an abstract landscape (Barnett 2018). The environment is cast in black agar, a mixture of agar powder and squid ink powder to provide a nutrient-rich and high-contrast background. The two organisms are placed in the environment a few inches apart. As they explore their new territory they pulse towards each other. After a gradual approach, there is a moment of hesitation before physical contact is made, immediately followed by a fusion event – a tubular network forming across the divide (Figure 7.9). As observed by Percy Smith in his film, *Magic Myxies*, ‘when two myxies meet they immediately join forces and flow away together’ (Smith and Field: 1931: 04:45). Where there were two organisms, there is now one – perfectly integrated and operating as a single entity. Much recent scientific research has focused on the process of this fusion, particularly in relation to questions of learning and protocognition. Experiments have demonstrated that the act of fusion, not only conjoins cellular matter but enables slime moulds to pass habitual learning (learning gleaned from its encounters with its environment) onto other non-habituated slime moulds (Vogel and Dussutour 2016; Vallverdú et al. 2018), the organisms’ exchanging and merging chemical knowledge about their surroundings.

Definitions of intelligence are now expanding to embrace non-neuronal forms of cognition across many living systems which embody environmental dialogue, organism reciprocity and information distribution (think of the array of recent research on mycelium networks and the ‘wood wide web’). The many-stranded forms of research concerned with this many-headed organism form an ‘ecological reticulum’ (Rheinberger 1997: 182), a network of interconnected concepts and stories which transcend disciplinary boundaries and epistemological systems.

I view my artistic experiments with slime mould as a form of dialogue between empirical, intuitive and explicit knowledge systems, as a means to draw out the biological processes and relate to wider concepts of embodied cognition. My time-lapse studies do not follow the conventions of scientific or natural history filmmaking and they do not present any fixed narrative. Instead, I hope that the visual tropes of time-lapse photography allow the organism to speak on its own terms in a performative way. Through its oscillatory rhythmic flow of cytoplasm,

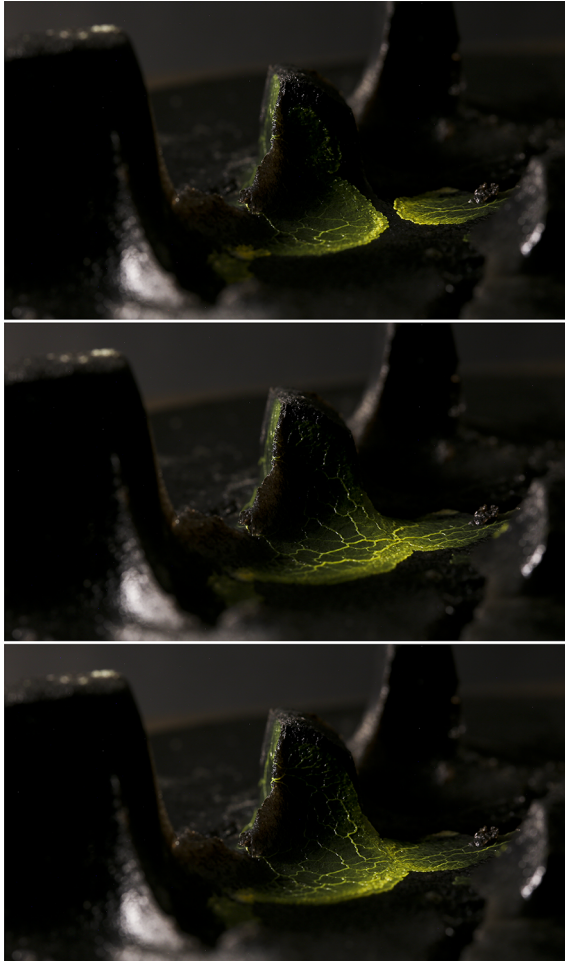


FIGURE 7.9: Film stills from *The Physarum Experiments, Study No. 026: Intraspecies Fusion* (2018). © Heather Barnett.

through the constant pushing and pulling of internal forces, the slime mould reveals the ‘cognitive’ activity of a chemically sensing body, mediated by my interventions.

The titling of the films, a series of numbered ‘studies’, is purposeful. Used in the domains of both science and art, the ‘study’ implies a focus on learning through experimentation. A ‘study’ does not suggest the creation of fully resolved artworks or results, but a mode of enquiry and a state of being in perpetual process. Through the various technical, aesthetic and conceptual choices of experimental design – the level of intervention, shifting cameras positions and ranging interval times – I

have built an eclectic portfolio of slime mould studies which are represented and disseminated in different ways (Barnett n.d.b). In addition to being exhibited as artistic works with the usual conventions that apply in that context, the films are also made available online posted on a YouTube channel (Barnett n.d.a). They are listed under a Creative Commons license which grants others non-commercial use of the material. In recent years, *The Physarum Experiments* have been appropriated and integrated into science documentaries, including *Is this slime mould intelligent without a brain?* (Whatson 2019), a gothic opera *Polia & Blastema* (Merhige 2021), an experimental film *Queering Di Teknologik* (Smith 2019) and a feature-length documentary film about Delhi's air pollution *Invisible Demons* (Jain 2021). As the slime mould aggregates its cellular mass and propagates through its environment, I am curious as to the myriad of interpretations of its behaviours and the attribution of ideas carried (unwittingly) by this curious organism. The slime mould – as a metaphorical and physical body – facilitates the propagation of ideas. In the same way that I cannot control the outcome of my interactions with the organism, I choose not to control how others interpret and represent the organism I have captured on camera.

Relational devices: Drawing out and drawing in

Physarum polycephalum offers us something like the degree zero of sentience and of decision-making. Its mode of thinking doesn't involve concepts, or representations, or intentional objects, or self-awareness, or even an underlying unity of experience; it leaves out most of the things that philosophers have traditionally considered to be necessary or intrinsic to thought. And yet, it feels, and ponders, and decides.

(Shaviro 2016: 213)

My artistic and intellectual interest in the slime mould is multi-faceted: as a subject, I find it fascinating, as a medium it has inherent aesthetic and behavioural characteristics which can be 'worked with', and as a metaphorical device it relates to many epistemological and ontological concepts. The time-lapse studies, in combination with the other methods of interdisciplinary enquiry I employ, collectively form an experiential and practice-driven 'experimental system'. The films propagate through different contexts and interpretations, they inform workshops and collective experiments, and they help me better understand the inherent properties of the organism itself, with the different elements coalescing and feeding back into each other. Historian of science, Hans-Jörg Rheinberger, defines experimental systems as an assemblage of phenomena, materials, processes and concepts all

‘packaged together’ (1997: 28). Within the scientific research he critiques, experimental systems operate as ‘vehicles for materialising questions, [which] inextricably cogenerate the phenomena or material entities and the concepts they come to embody’ (1997: 28). The slime mould embodies a vast number of concepts and phenomena – in literal, material and metaphorical terms. As a collective entity, many cells work cooperatively as a supercell, the organism lends itself to practices of co-generation and co-enquiry. I see my work with slime mould as sympoetic (Haraway 2016; Dempster 2000) – collectively producing – not in a truly collaborative way (clearly the slime mould does not choose to work with me), but in its capacity to embody a multitude of diverse concepts and concerns simultaneously. This assemblage – of organism, material and environmental interactions – can bring together different modes of knowledge, merging the explicit findings of scientific research with the tacit understanding from observation and experience. The staging of the organism, through this assemblage, creates feedback loops between slime mould and environment, between slime mould and human, and between slime mould and itself.

The slime mould, simultaneously one and many, offers a rich philosophical ‘discourse object’ (Rheinberger 1997), inviting us to speculate ... on the nature of self and other, on the identity of the individual and the collective and on the fundamental building blocks of intelligence. Through *looking at* and *looking with* other life forms, I suggest that we might shift our ontological assumptions. As Shaviro argues, ‘slime molds allow us to observe the mechanisms of thought in something like their primordial form’ (2016: 212) – a mode of thought that is distributed and dynamic, highly attuned to its environmental conditions. Neurons and oscillators alike require feedback loops for decision-making to take place and for any notion of thought to emerge, with elaboration and amplification in the system.

The purpose of the film studies, and indeed of this essay, is to tell visual stories of exceptional single-celled intelligence and invite one species (human) to observe and engage with another (slime mould) with fresh eyes and heightened appreciation. The intention is not merely to depict the slime mould as a biological object of curiosity, but to *draw out* its inherent behaviours as a subject and *draw in* the observer to meet another species halfway (Barad 2007). The work of Anderson-Tempini, Dupré and Wakefield, and the focus of this book, centres on drawing as a process by which we can better conceptualize and visualize the complex processes of life. To *draw* is to represent and make manifest, but it is also to pull towards, to draw closer, to *draw in*. The time-lapse process is intended to mediate between the relative physiological limits of perception and *draw out* that which cannot ordinarily be seen in human time and space. To *draw out* is to entice, to lure something out, to tease into being. A process of gradual extraction, *drawing out* is to prolong, to lengthen the time, implying a pulling of threads or of information (Merriam-Webster n.d.). In human

terms, it can mean to induce someone to speak openly, to reveal true feelings. In slime mould terms, it means to amplify processes of life which lie beyond our perceptual grasp and to scale up the organism (literally and metaphorically) in the hope of creating a relational space between two radically different spatiotemporal worlds.

In this chapter, I have explored the processes of life at play within *Physarum polycephalum*. I have introduced different aspects of the multi-faceted scientific enquiry seeking to better understand its fundamental forces and capabilities. I have discussed selected time-lapse studies I have created, working directly with the organism. The intention of this reciprocal interplay – between slime mould and human – is an invitation for an aesthetic pondering on disparate life forces and modes of existence. Whilst we can only ‘grasp the slime mold’s experience partially and indirectly, by its actual behavior and by the traces of evidence that it leaves behind’ (Shaviro 2016: 215), the temporal amplification offered by technological mediation permits access to some tacit understanding of the modes of decision making which occur within the organism as it operates in constant dialogue with its Umwelt. This relational encounter may encourage us to challenge our own definitions of intelligence, where human-centric (and therefore neuronally biased) positions are called into question by an embodied and chemically sensitive form of knowing. But this is not purely an altruistic exercise in ontological speculation. If humans can contemplate the subjective experience of the slime mould perhaps, we can, in turn, reflect on our own sensorial world and think about how decisions are made in dialogue with our own environment.

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