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 GaIápagos 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

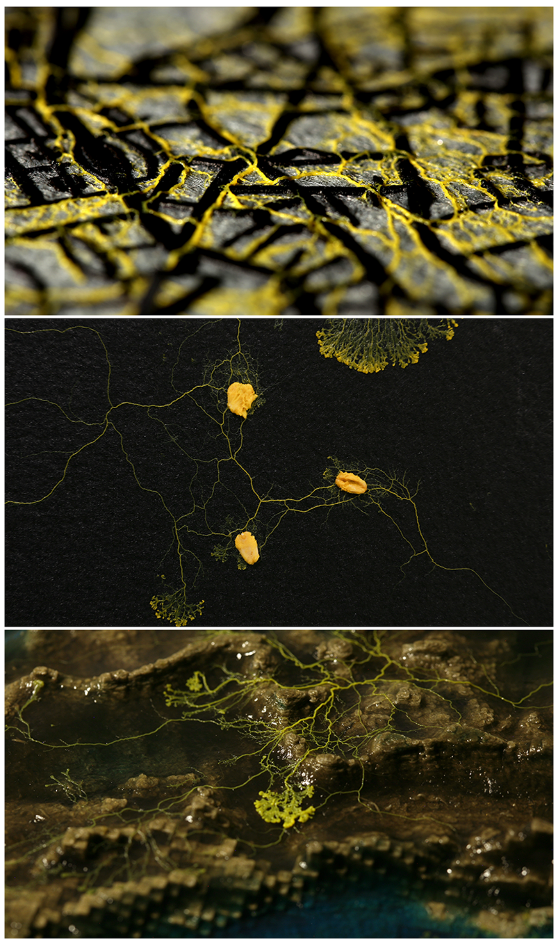

FIGURE 7.1: Still images from the slime mould studies *The Physarum Experiments*. © Heather Barnett.

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,

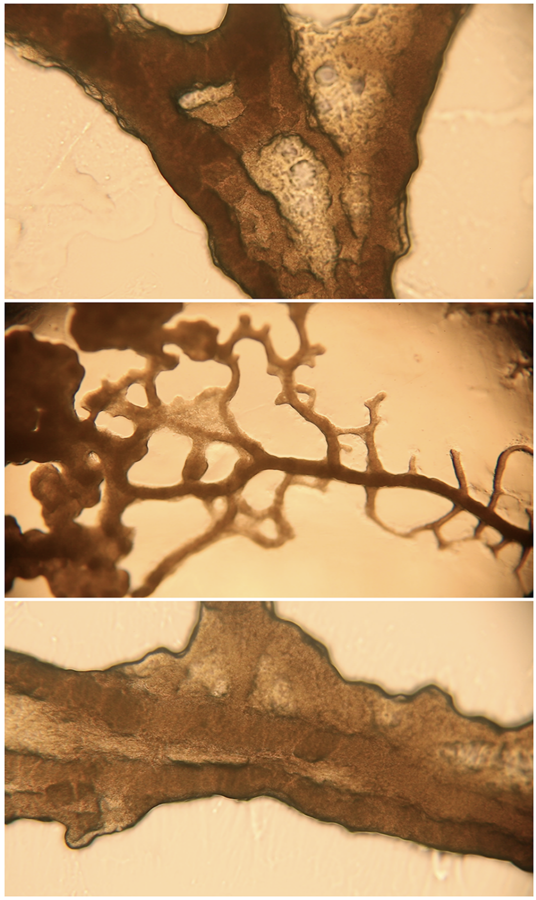

FIGURE 7.2: Still images from *The Physarum Experiments, Study No.020: Streaming*, showing the flow of nutrients and chemical information within the network of dynamic veins (2013). © Heather Barnett.

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).

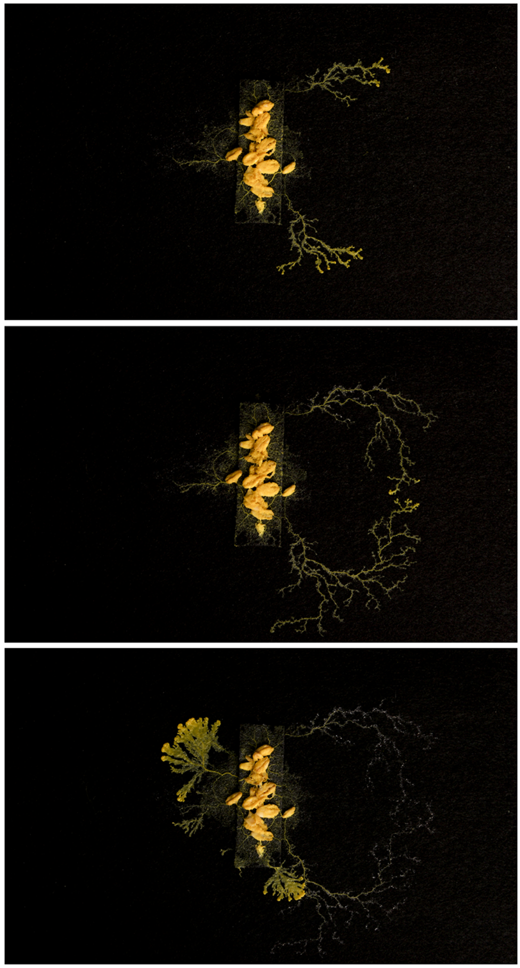

FIGURE 7.4: Still images from *The Physarum Experiments, Study No. 011: Observing Growth over 136 hours* (2009). From top-down: growth trajectories; point of recognition; change of direction. © Heather Barnett.

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 super-cell, 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

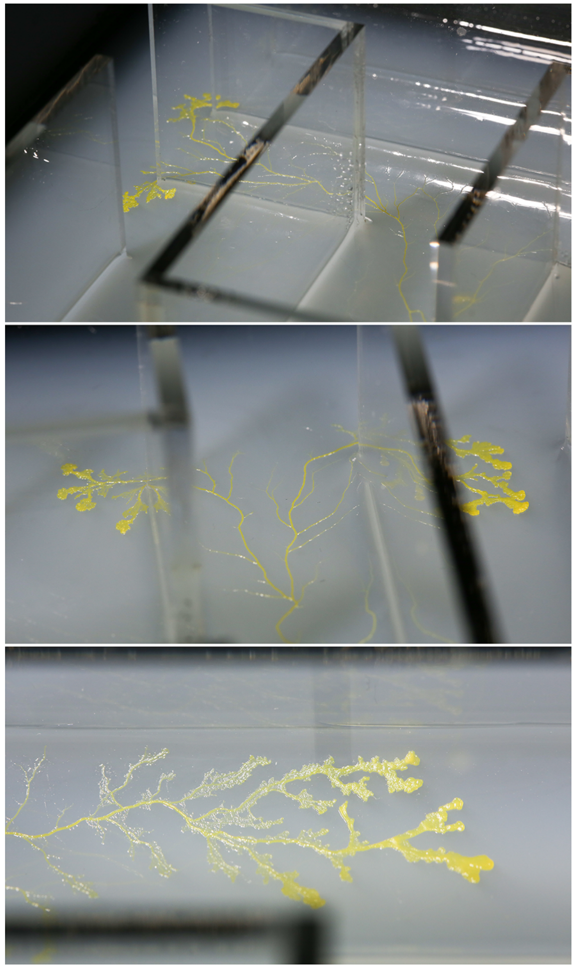

FIGURE 7.6: Film stills from *The Physarum Experiments, Study No. 019: The Maze* (2013). © Heather Barnett.

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

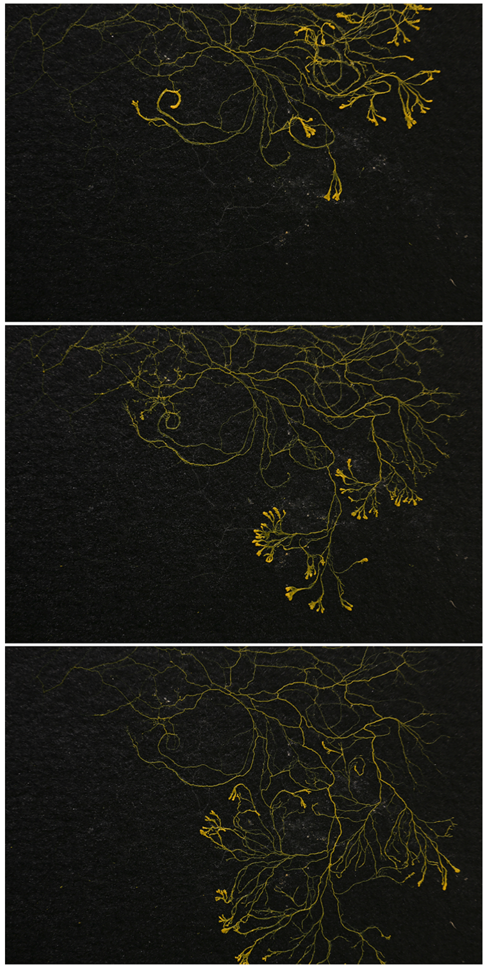

FIGURE 7.7: Film stills from *The Physarum Experiments, Study No. 022: Starvation Fireworks* (2016). © Heather Barnett.

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,

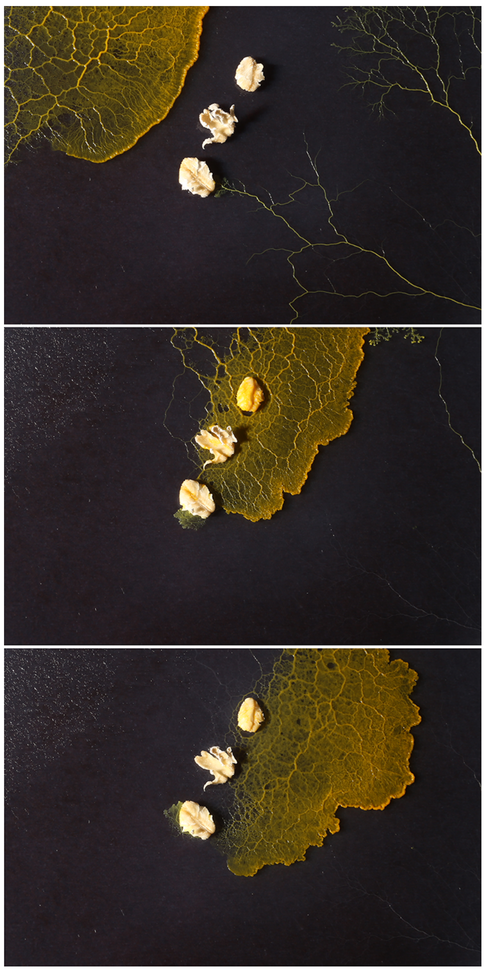

FIGURE 7.8: Film stills from *The Physarum Experiments, Study No. 024: Interspecies Encounter* (2016). © Heather Barnett.

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,

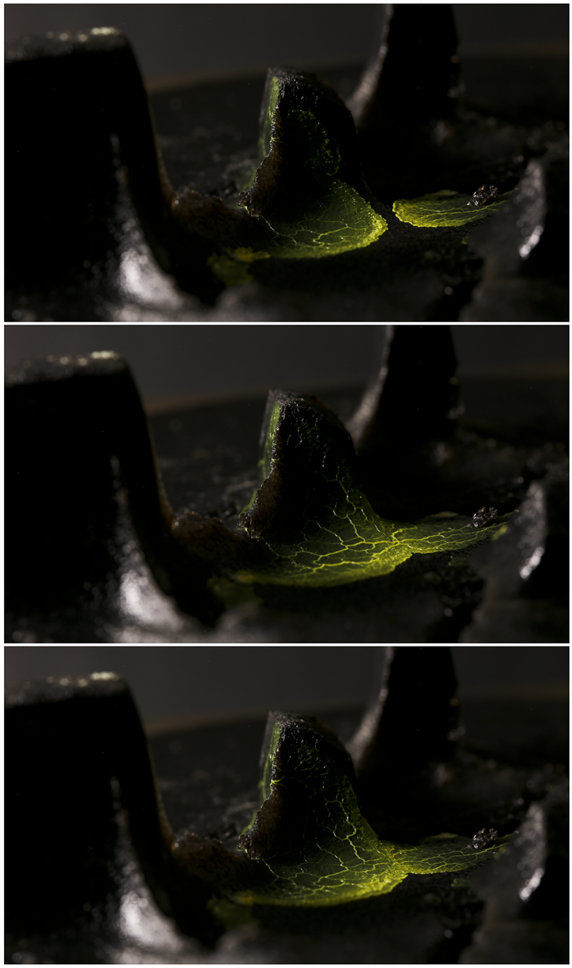

FIGURE 7.9: Film stills from *The Physarum Experiments*, *Study No. 026: Intraspecies Fusion* (2018). © Heather Barnett.

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 Teknolojik* (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.

REFERENCES

'Autumn' (2013), *The Great British Year*, Episode 4 (last broadcast 20 August 2020, UK: BBC) https://www.bbc.co.uk/programmes/p01dflmb. Accessed 19 September 2021.

Barad, Karen Michelle (2007), *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Durham: Duke University Press.

Barkham, Patrick (2016), 'Small wonders: The tiny world of F. Percy Smith', *The Guardian*, 26 October, https://www.theguardian.com/film/2016/oct/26/acrobatic-flies-percy-smith-minute-bodies-film-stuart-staples-bfi. Accessed 20 August 2021.

Barnett, Heather (2009), *The Physarum Experiments, Study No. 011: Observation of Growth over 136 hours* [Time-lapse HD video], YouTube, August, https://youtu.be/Lc9Y4M5vvtE. Accessed 15 September 2021.

Barnett, Heather (2013a), *The Physarum Experiments: Study No. 019: The Maze* [Time-lapse HD video], YouTube, May, https://youtu.be/SdvJ20g4Cbs. Accessed 15 September 2021.

Barnett, Heather (2013b), *The Physarum Experiments, Study No. 020: Streaming* [Microscopy HD video], YouTube, June, https://youtu.be/kuaF5g3RnBo. Accessed 15 September 2021.

Barnett, Heather (2016a), *The Physarum Experiments, Study No. 022: Starvation Fireworks* [Time-lapse HD video], YouTube, October, https://youtu.be/5tYKYpQzu6E. Accessed 15 September 2021.

Barnett, Heather (2016b), *The Physarum Experiments, Study No. 024: Interspecies Encounter* [Time-lapse video], YouTube, October, https://youtu.be/cbEirySHYXc. Accessed 15 September 2021.

Barnett, Heather (2018), *The Physarum Experiments, Study No. 026: Intraspecies Fusion* [Time-lapse HD video], YouTube, December, https://youtu.be/wSCZSBcZNDA. Accessed 15 September 2021.

Barnett, Heather (2019a), 'Being other than we are …', *PUBLIC*, 31:59, pp. 158–69.

Barnett, Heather (2019b), 'Many-headed: Co-creating with the collective', in A. Adamatzky (ed.), *Slime Mould in Arts and Architecture*, Denmark: River Publishers, pp. 13–37.

Barnett, Heather (n.d.a), '*The Physarum Experiments playlist*', YouTube, https://www.youtube.com/playlist?list=PL052BA2BC570A3852. Accessed 28 September 2021.

Barnett, Heather (n.d.b), '*The Physarum Experiments*', Artist Website, http://heatherbarnett.co.uk/work/the-physarum-experiments/. Accessed 10 September 2021.

Beekman, Madeleine and Latty, Tanya (2015), 'Brainless but multi-headed: Decision making by the acellular slime mould *Physarum polycephalum*', *Journal of Molecular Biology*, 427:23, pp. 3734–43, https://doi.org/10.1016/j.jmb.2015.07.007. Accessed 9 November 2022.

Boisseau, Romain, Vogel, David and Dussutour, Audrey (2016), 'Habituation in non-neural organisms: Evidence from slime moulds', *Proceedings of the Royal Society B: Biological Sciences*, 283:1829, p. 20160446, https://doi.org/10.1098/rspb.2016.0446. Accessed 9 November 2022.

Brown, Stuart (2016), 'London Film Festival 2016 Catalogue', BFI. 60th BFI London Film Festival: 5–16 October.

Deleuze, Gilles and Guattari, Felix (1987), *A Thousand Plateaus: Capitalism and Schizophrenia*, Minneapolis: University of Minnesota Press.

Dempster, Beth (2000), 'Sympoietic and autopoietic systems: A new distinction for self-organizing systems', in *Proceedings of the World Congress of the Systems Sciences and ISSS 2000*, pp. 1–18.

Elkins, James (2016), 'Social networks of non-human seeing', *Antennae: The Journal of Nature in Visual Culture*, 37, pp. 91–103.

Field, Mary, Percy Smith, F. and Durden, J. V. (1942), *Ciné-Biology*, Middlesex, New York: Pelican Books.

Grabham, Tim and Sharp, Jasper (2014), *The Creeping Garden*, UK: Arrow Academy.

Haraway, Donna (2016), *Staying with the Trouble: Making Kin in the Chthulucene*, Durham: Duke University Press.

Jain, Rahul (2021), *Invisible Demons – Tuhon merkit*, India, Finland, Germany: Ma.Ja.De Filmproduktion/Participant/Toinen Katse.

Johnson, Steven (2002), *Emergence: The Connected Lives of Ants, Brains, Cities and Software*, London: Penguin Books.

Latty, Tanya and Beekman, Madeleine (2011), ‘Speed–accuracy trade-offs during foraging decisions in the acellular slime mould *Physarum polycephalum*’, *Proceedings of the Royal Society B: Biological Sciences*, 278:1705, pp. 539–45, https://doi.org/10.1098/rspb.2010.1624. Accessed 9 November 2022.

Long, Max (2020), ‘The ciné-biologists: Natural history film and the co-production of knowledge in interwar Britain’, *The British Journal for the History of Science*, 53:4, pp. 527–51, https://doi.org/10.1017/S0007087420000370. Accessed 9 November 2022.

Masui, Mana, Satoh, Shinobu and Seto, Kensuke (2018), ‘Allorecognition behavior of slime mold plasmodium – *Physarum rigidum* slime sheath-mediated self-extension model’, *Journal of Physics D: Applied Physics*, 51:28, p. 284001, https://doi.org/10.1088/1361-6463/aac985. Accessed 9 November 2022.

Merhige, E. Elias (2021), *Polia & Blastema: A Cosmic Opera*, US: Strangeloop Studios

Merriam-Webster (n.d.), ‘draw out’, Merriam-Webster online, https://www.merriam-webster.com/dictionary/draw%20out. Accessed 28 August 2021.

Nakagaki, Toshiyuki, Yamada, Hiroyasu and Tóth, Ágota (2000), ‘Maze-solving by an amoeboid organism’, *Nature*, 407:6803, p. 470, https://doi.org/10.1038/35035159. Accessed 9 November 2022.

Nakagaki, Toshiyuki, Yamada, Hiroyasu and Tóth, Ágota (2001), ‘Path finding by tube morphogenesis in an amoeboid organism’, *Biophysical Chemistry*, 92:1&2, pp. 47–52, https://doi.org/10.1016/s0301-4622(01)00179-x. Accessed 9 November 2022.

Nakamura, Akio and Kohama, Kazuhiro (1999), ‘Calcium regulation of the actin-myosin interaction of *Physarum polycephalum*’, *International Review of Cytology*, pp. 53–98, https://doi.org/10.1016/s0074-7696(08)60157-6. Accessed 9 November 2022.

Reid, Chris R., Beekman, Madeleine, Latty, Tanya and Dussutour, Audrey (2013), ‘Amoeboid organism uses extracellular secretions to make smart foraging decisions’, *Behavioral Ecology*, 24:4, pp. 812–18, https://doi.org/10.1093/beheco/art032. Accessed 9 November 2022.

Reid, Chris R., MacDonald, Hannelore, Mann, Richard, Marshall, James, Latty, Tanya and Garnier, Simon (2016), ‘Decision-making without a brain: How an amoeboid organism solves the two-armed bandit’, *Journal of The Royal Society Interface*, 13:119, p. 20160030, https://doi.org/10.1098/rsif.2016.0030. Accessed 9 November 2022.

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

Saigusa, Tetsu, Tero, Atsushi, Nakagaki, Toshiyuki and Kuramoto, Yoshiki (2008), ‘Amoebae anticipate periodic events’, *Physical Review Letters*, 100:1, p. 018101, https://doi.org/10.1103/PhysRevLett.100.018101. Accessed 9 November 2022.

‘Secrets of Nature’ (1922–34), British Instructional Films, UK: BBC, https://secrets-of-nature.co.uk/. Accessed 1 September 2021.

Seifriz, William and Zetzmann, Marie (1935), ‘A slime mould pigment as indicator of acidity’, *Protoplasma*, 23:1, pp. 175–79, https://doi.org/10.1007/BF01603385. Accessed 9 November 2022.

Shaviro, Steven (2016), 'Thinking like a slime mold', in *Discognition*, London: Repeater Books, pp. 193–215.

Smith, Percy F. and Field, Mary (1931), *Magic Myxies*, British Instructional Films, http://www.screenonline.org.uk/film/id/1269007/credits.html. Accessed 23 May 2021.

Smith, Timothy (2019), *Queering di Teknolojik*, UK: Lucid Films

Smith-Ferguson, Jules, Reid, Chris R., Latty, Tanya and Beekman, Madeleine (2017), 'Hänsel, Gretel and the slime mould – How an external spatial memory aids navigation in complex environments', *Journal of Physics D: Applied Physics*, 50:41, p. 414003, https://doi.org/10.1088/1361-6463/aa87df. Accessed 9 November 2022.

Uexküll, Jacob Von (1934), 'A stroll through the worlds of animals and men: A picture book of invisible worlds', Originally published in *Instinctive Behavior* (ed. and trans. C. H. Schiller), Madison: International Universities Press, 1957, pp. 5–80. Reprinted in 1992 in *Semiotica* 89:4, pp. 319–91, https://doi.org/10.1515/semi.1992.89.4.319. Accessed 9 November 2022.

Vallverdú, Jordi, Castro, Oscar, Mayne, Richard, Talanov, Max, Levin, Michael, Baluska, Frantisek, Gunji, Yukio, Dussutour, Audrey, Zenil, Hector and Adamatzky, Andrew (2018), 'Slime mould: The fundamental mechanisms of biological cognition', *Biosystems*, 165, pp. 57–70, https://doi.org/10.1016/j.biosystems.2017.12.011. Accessed 9 November 2022.

Vogel, David and Dussutour, Audrey (2016), 'Direct transfer of learned behaviour via cell fusion in non-neural organisms', *Proceedings of the Royal Society B: Biological Sciences*, 283:1845, p. 20162382, https://doi.org/10.1098/rspb.2016.2382. Accessed 9 November 2022.

Whatson, Doctor (2019), 'Is this slime mold intelligent without a brain?', YouTube, https://www.youtube.com/watch?v=f2cSz14Y_wY. Accessed 1 October 2021.