ARTISTS' ARTICLE

Slime Mold and Network Imaginaries

An Experimental Approach to Communication

SELENA SAVIĆ AND **SARAH GRANT**

ABSTRACT

Physarum polycephalum, or slime mold, is an acellular organism extensively studied in scientific experiments and artistic engagements. Artist and critical engineer Sarah Grant collaborates with architect and researcher Selena Savić on hybrid bio-networking experiments with slime mold as an approximation of a computer network. They study communication as an organic process, rethinking networks' inherent technicity through encounters with a living organism. They discuss network imaginaries situated in the way slime mold forages for food: at once transmitting and materializing its experiences, constrained and conditioned by the environment. The results of this work are imaginative accounts of adaptive network infrastructure and protocols.

This artistic inquiry into communication networks imaginaries aspires to rethink networks' inherent technicity through encounters with a living organism. It is informed by Sarah Grant's artistic work with the acellular organism *Physarum polycephalum*, generally known as slime mold. Over the past six years, Grant has been exploring slime mold's capacity to be a part of hybrid bioelectrical circuits [1] or visceral media approximations to computer network protocols and topologies [2]. The project presented here weaves Grant's artistic practice, which increasingly involves growth processes, with communication networks moving information across space, or, in the case of slime mold, across the organism's body. As part of a short residency at Institute Experimental Design and Media Cultures (IXDM) in Basel, Switzerland, Grant collaborated with architect and researcher Selena Savić, who works on a project that critically examines the role of technology in commoning practices [3,4] from an interest in materiality of networks. Inspired by the work of political economist Elinor Ostrom on economic governance and the commons, commoning is proposed as alternative to the latest forms of capitalism [5,6]. In this paper, Grant and Savić combine their voices into a temporary "we," representing a shared interest in networking through the lens of slime mold behavior.

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SLIME MOLD AND NETWORKING

Our artistic approach to the exploration of slime mold as networks is characterized by a spatialized thinking setup with three tectonic planes of knowledge and interest. The first plane is the behavior of the slime mold: an amoeba continuously transforming its body into an efficient network of nutrients as it seeks food and the favorable environmental conditions of shade and moisture. The second plane of interest is network infrastructure and its protocols, in particular the techniques for transporting information. The third plane of interest is communication: the way preferences or meaning move across infrastructures, a sort of projection of organic behavior on networks' technicity.

Akin to the way ancient Greek mathematician Thales of Miletus could calculate the height of the Great Pyramid of Cheops by comparing the length of its shadow to the shadow of his walking stake, we observed slime mold's networking body through the shadow communication cast upon the network topology habitats we created. This mediated approach gave us access to a speculative account of computer networks' capacity to self-optimize, inspired by the slime mold's capacity for reconfiguration. Furthermore, we experimented with the slime mold as a proxy to avoid the complexity, cost, and environmental impact of running experiments over ordinary communications infrastructure.

We created a series of habitats as experimental contexts using what we already knew about slime mold's behavior as a starting point. These experiments included arranging food sources in different topological configurations and placing obstacles to approximate scenarios of even and uneven distribution of both scarce and abundant resources.

We disclose information on two levels: One is the technical description of our encounters with slime mold, which takes the tone of scientific reporting. On this level, an objective and impersonal voice necessarily reduces slime mold's behavior

 https://doi.org/10.1162/leon_a_02248

to a model or a metaphor of communication networks. Second, we recognize that any such effort accompanies the specific, situated character of our encounters with slime mold, which requires accounting for our heterogenous and partial perspectives.

Knowing Slime Mold in Nature, Lab, and Artist Studio

Physarum polycephalum is an acellular organism whose life cycle includes three distinct stages: one in which it looks for food, as *plasmodium*; a second, reproductive stage, when it develops *sporangia*; and a third, hibernate stage, as *sclerotium*. In its feeding stage it resembles a small patch of bright yellow mucous (Fig. 1). The cell contains a multitude of individual nuclei: its many heads (*polycephalum*). It can take many shapes, and the size of a slime mold ranges from several millimeters to the size of a table.

In nature, slime mold slowly creeps through forest floors to feed on damp leaf litter, bacteria, fungi, and other microorganisms. Once it locates all nearby food sources, it contracts back on itself, strengthening the connections between the best sources, thereby creating an optimal network for digestion and distribution of nutrients. Traces of extracellular slime, which function as spatial memory, are left behind (Fig. 2). When exposed to heat or light and unable to find food, the *plasmodium* enters its reproductive phase and develops sacs of spores called *sporangia*. Once environmental conditions are favorable again, the spores emerge from these fruiting bodies, joining together to form new *plasmodia*. The life cycle begins again.

Physarum polycephalum in the lab (Fig. 2) exhibits behavior that has been called proto-intelligent or cognizant: It is able to solve mazes and determine the shortest paths in a network. Scientists studied slime mold's ability to "learn," "memorize" events and routes, "make decisions," selectively search for food, and solve a range of complex challenges [7]. A well-known example is the Tokyo railway experiment [8], which demonstrated how *Physarum polycephalum* networks, connecting food sources arranged as geographical locations of cities in the Tokyo area, reproduced the layout and transport efficiency of the actual rail network. These experiments are often attuned to suggesting how slime mold can be used

Fig. 1. Slime mold in nature. Photo taken 31 January 2015 in Christchurch City, Canterbury, New Zealand. (Bernard Spragg, public domain)

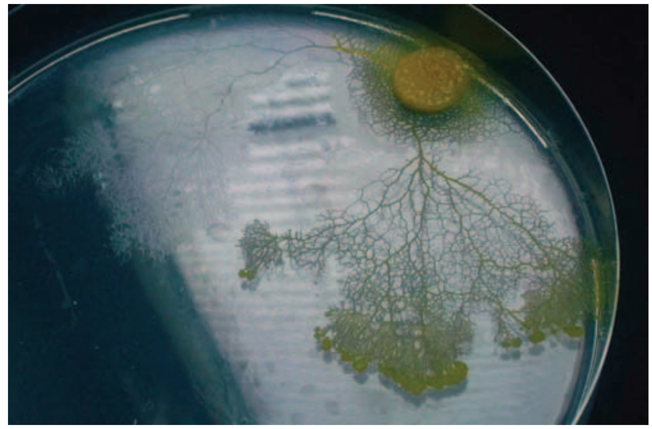

Fig. 2. Slime mold in the laboratory shows different parts of the plasmodium: inoculation of plasmodial culture (yellow disk), the tubule network and its search front, and extracellular slime from previous exploration. (© Audrey Dussutour)

to inform designs of new networks and environmental infrastructure by human engineers.

Information moves across the organism as a peristaltic wave of information on food availability, traveling by cross-sectional contraction of tubes in a "feedback loop," triggered by contact with a food source [9]. This chemical sensing and signaling, known as chemotaxis, propels the cell to migrate toward adequate (and move away from inadequate) food sources.

Artistic engagements with *Physarum polycephalum* extend the space of its agency: Artists search for ways this living organism can inform our understanding of social and cultural interactions. Heather Barnett considered a collaborative, coauthor relation with the slime mold, "a process of negotiation between an artist and a single-celled organism" [10]. Barnett engaged in playful pedagogies, such as in her work *Nodes and Networks* [11], exploring pollution, crime, or gentrification in urban contexts. In a different mode of operation, Barnett's *Being Slime Mould* offered a collective experience to address directly the biological effects of the behavioral rules observed in slime mold and explore its nonhuman perspective [12]. Media artist Vanessa Lorenzo works with microflora and fauna to challenge and reflect on our presumed individuality [13]. Lorenzo's projects also address the invisible diversity of the contemporary urban environment, interested in the evocative visual language of bacteria, fungi, and slime molds. Theresa Schubert used slime mold as an aesthetic catalyst but also to question her connection with the other (humans and nonhumans), often through skin [14]. Another relevant approach is that of Agnes Cameron, who examined the use of slime mold as a model for network resilience [15]. Cameron pursued the interest in self-optimization of networked communication by using slime mold organisms to model self-organizing telecommunication networks.

Sarah Grant's work looks at social interactions' reconfiguration by the design, deployment, and locality of communication networks. In *Subnodes* and *You Are Here,* she installed small, portable, local area wireless computer networks that acted as geocached digital habitats for social interactions within a close physical space [16,17]. More recently, together with Colombian artist Juan Pablo García Sossa, Grant has been developing a wide area wireless peer-to-peer community network designed to facilitate a lateral, intertropical cultural exchange across great distances [18].

In her work with slime mold, Grant is interested in centering the network itself as the subject, observing how it responds to its environment. She regards the slime mold as a living manifestation of a communications network that adapts in real time to dynamic environmental conditions. This interest motivated the explorations described below.

MODELING NETWORK TOPOLOGIES WITH *PHYSARUM POLYCEPHALUM*

We explored how the growing body of slime mold would articulate and adapt to its environment in a dialogue with the different spatial configurations of attractants and repellents. Based on literature and previous experiments, we assumed that *Physarum polycephalum* would try to overcome obstacles to get to its most preferred food (honey), that it would prefer oats over pasta, and that it would avoid salty or spicy foods.

We designed and built nine experimental network topologies to examine how slime mold could be used to model information flow through a network driven by different food distribution configurations (Fig. 3):

a. decentralized, equal linear distribution (1a)
b. decentralized, scattered scarcity (2a, 2b, 2c)
c. centralized, circles (3a)
d. equal field distribution in triangle or square (4a, 4b)
e. scarcity vs. abundance (5a, 5b)

We placed slime molds in custom-made enclosures treated with a ground of agar (Fig. 3, 1a–5b). We carefully placed food sources as attractants and repellents to articulate different network topologies (i.e. centralized or decentralized) to analyze and speculate upon. We played with spacing between the food sources and their regularity and painted food with natural colorings so that we could monitor how the cell moves information across its body. We observed how slime mold grew across these configurations.

PREDICTABLY UNPREDICTABLE GROWTH

The nine slime mold cells grew by expanding and retracting in all directions until they detected a source of nutrients. They often “economized” on movement: If oats were placed close to each other (about 1 cm), the body would quickly establish a distributed network connecting them. When food was placed in concentric circles, slime mold first consumed closer food sources, making “rings” across pieces of pasta, before exploring the space centripetally. In scarcity scenarios (Fig. 3, 2a–c), it grew around densely concentrated food sources before foraging to meet its other parts. The exploration of equally distributed food sources (Fig. 3, 4a and 4b) worked as expected: Slime mold moved, exploring farther and consuming nearby, gradually covering the area evenly (Fig. 4).

The interaction with honey was different from our expectations. We used honey to stimulate *Physarum polycephalum* to overcome obstacles, but it avoided it in large movements. In a centralized setup, slime mold explored the dish two or three times in circles before reaching for honey (Fig. 4, left). In the setup where we hid honey behind a “wall” of spice (Fig. 5, right), the slime mold took a week before eventually reaching for honey. We consider that the specific food coloring could have caused the unexpected behavior. We were able to observe the flow of information from different food sources marked by their color: blue honey, red pasta, or yellow oats (Fig. 6). We consider how this could determine optimal paths for transmissions in the different setups, including a reflection on possible spread of misinformation (e.g. repellent honey). We take this as a demonstration that the way communication works in a network is conditioned by several

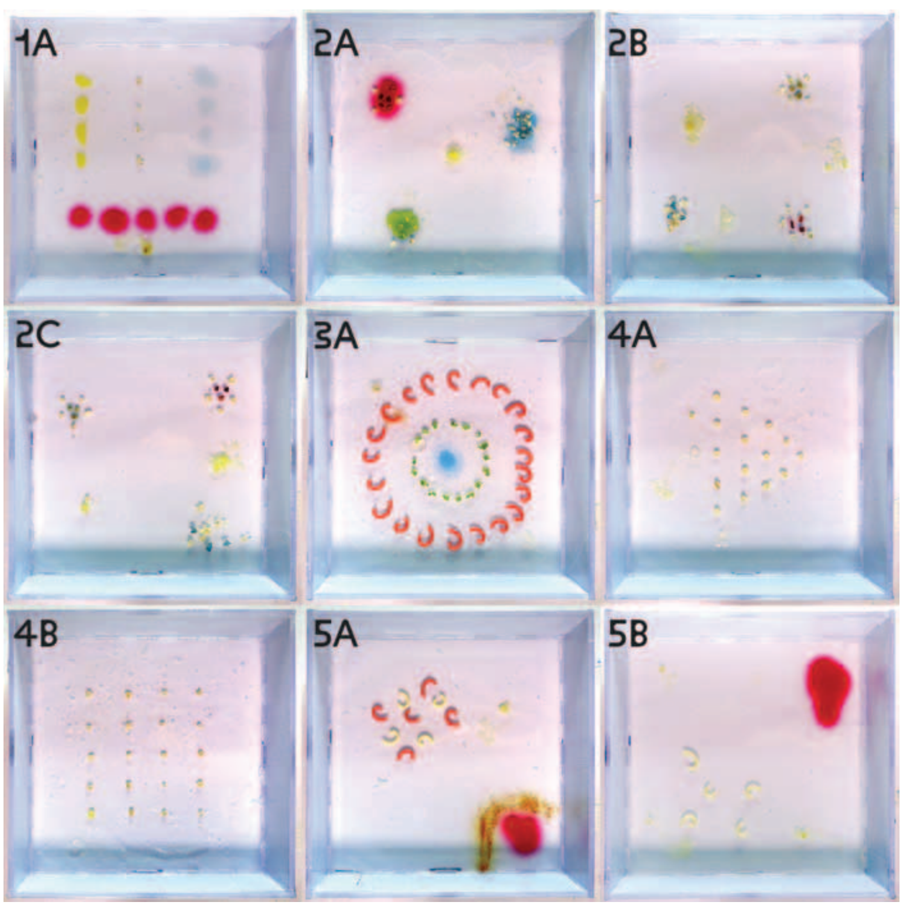

Fig. 3. Nine square dishes with initial conditions: 1a, 2a, 2b | 2c, 3a, 4a | 4b, 5a, 5b. (© Sarah Grant)

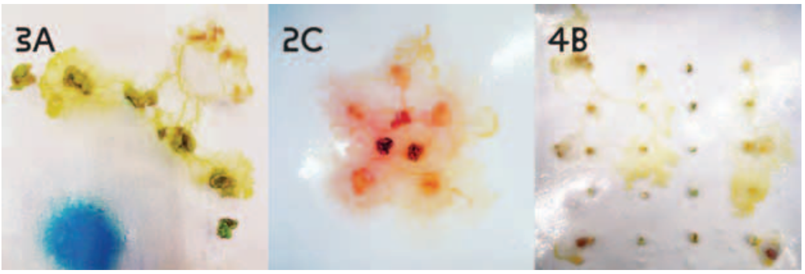

Fig. 4. The growth of three experimental scenarios: 3a, 2c, 4b. (© Sarah Grant)

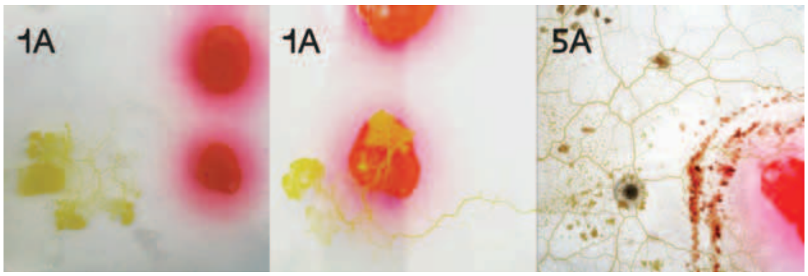

Fig. 5. Honey: the dislike and eventual consumption, scenarios: 1a, 1a, 5a. (© Sarah Grant)

factors simultaneously: distances and preferences, as well as unpredictable factors. The body of the slime mold organism "computes" and "distributes" information (and resources, food) in ways "optimal" for its survival but telling of complex entanglements of motivations that are more interesting to observe than to resolve.

Rethinking Networks with Slime Mold

We set out to imagine how network protocols could emulate some of the organic processes that we observed in our experiments. We recognize that some of the decentralized networking technologies, such as mesh networking, already incorporate aspects of this organicity. Mesh networks gained prominence in ad hoc networking situations, such as disaster recovery. Often used as alternative, independent modes of information exchange in political struggle (Athens Wireless Metropolitan Network in 2015 or Occupy.here in 2011), mesh networks are praised for their resilience and low planning requirements. For example, a device running the B.A.T.M.A.N. open mesh networking protocol [19] constantly broadcasts messages alerting nearby nodes of its existence and seeks to connect with them, thereby increasing network resilience.

Comparable to mesh networking, slime mold actively seeks food sources, fanning out and retracting. This behavior is already incorporated in the design of mesh networking protocols: They actively seek other nodes in order to dynamically extend the network. Thinking further with slime mold, we imagined extending these network protocols to include metadata about the current state of the network, taking a cue from the slime mold's capacity to chemically transmit environmental conditions and the location of an attractant or repellent across its entire body. Possible information includes bandwidth usage, energy levels, and responsiveness of network nodes, or environmental conditions.

We considered slime mold's capacity to adaptively reconfigure its network of food nodes. As nodes in its network were metabolized, the slime mold retracted, and abandoned nodes depleted of nutrients. Once there was no food left, the slime mold was found to retract in on itself, forming a hard, dehydrated scab as it entered the sclerotia phase. Thinking of this behavior in network terms, we recognize that different types of networks would require different kinds of adaptation to a lack of resources. For example, with wireless sensor networks (WSN), which are used to monitor physical or environmental conditions in the wild, the main challenges in design and deployment are network energy consumption, interaction of nodes, and capacity for self-configuration [20]. Could a sensor in the network send a signal to its nodes to enter a low power mode to preserve network integrity, in extreme cases even temporarily abandoning some nodes? Another example to consider is backbone networks that tie diverse networks together. The main issues in their performance are congestion and interference, addressable with topology control, which essentially reroutes network routes to reflect the current pattern of traffic demands [21]. We pro-

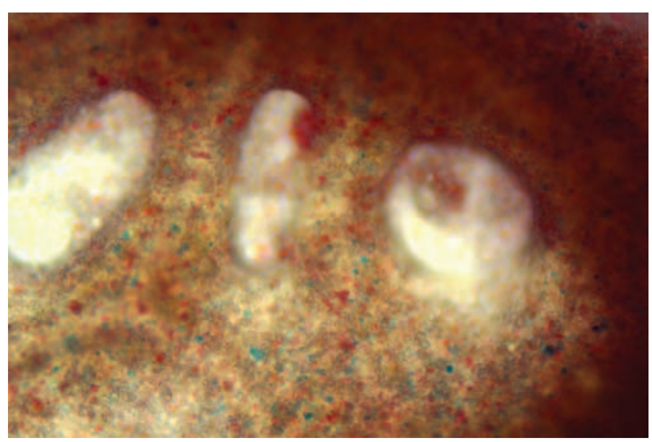

Fig. 6. Observation of food particles moving across the slime mold body under a digital microscope. (© Sarah Grant)

pose to consider how slime mold capacity to articulate the environment in terms of preferred food sources could serve as a model for rerouting.

Adjacent to this idea is the art project *The Solar Protocol*, recently released by Tega Brain, Alex Nathanson, and Benedetta Piantella [22]. It features a network of small solar-powered servers set up in different locations around the world, routing traffic through nodes with the most available energy.

The slime mold enters its reproductive phase when there is scarcity of food coupled with exposure to light. What would it look like for a communications network to enter a "reproductive phase"? We imagined a network of servers that initiates a process for bringing up replacement servers when the network suffers critical damage such as disk failure or power outage.

CONCLUSION

Slime mold has been extensively explored in science as an "informant" on network design and traffic routing because of its capacity to avoid obstacles, solve mazes, and compute shortest paths. We propose to open this relationship to mediation and let slime mold tell us about networking in an open-ended way. Our interest in slime mold is driven by an ambition to challenge the conceptual similarities and practical differences between the way slime mold's growing body articulates a network and the way this is interpreted in science and art.

Our discussion on rethinking the networks demonstrates a way to create and share imaginaries of network behavior through situated observations of a living, resilient organism. As artists, we have direct access to this organism and can model scenarios in which we study the behavior of slime mold. Rather than working with expensive proprietary hardware and software for running sophisticated network processes, we propose speculations that normally occur in engineering labs, available and accessible to an artistic practice.

In our explorations of the different scenarios, we do not seek predictions or optimizations of real outcomes. The interest in the way slime mold computes and communicates signals a practical, situated scope of this work. With the discussion on experimental outcomes and network imaginaries, we demonstrate the ability to move between the real world and its abstraction in a productive manner. Just as Grant's work is aesthetically determined but unconstrained to a single artistic or engineering domain, we work with and observe how slime mold articulates its environment. In this exploration, we simultaneously read the performativity of life-supporting processes (foraging for food) and the performance of the environment that conditions "efficient" strategies for slime mold.

Acknowledgments

We would like to thank Vanessa Lorenzo for providing us with samples of *Physarum polycephalum* to work with. Sarah Grant's residency within the Thinking Toys for Commoning project at the Institute Experimental Design and Media Cultures (IXDM) was financed by Swiss National Science Foundation project grant 175913.

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Manuscript received 1 June 2021.

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