Nodes and Networks

what slime mold can show us about

New York City

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 experiments 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.

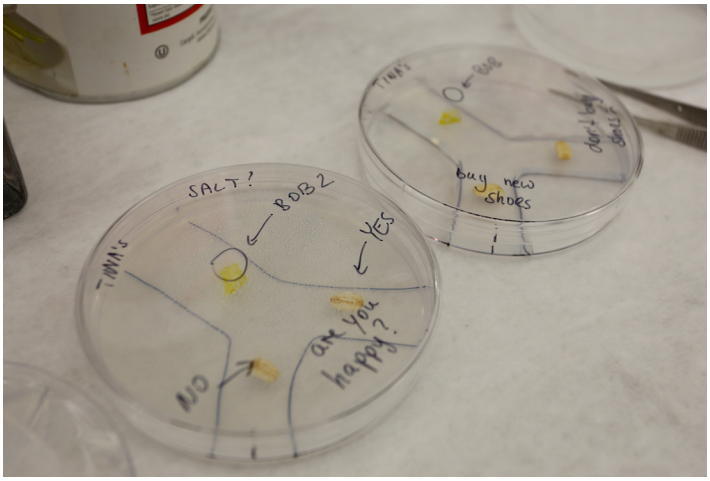
COLLECTIVE CREATIVITY

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).

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



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.

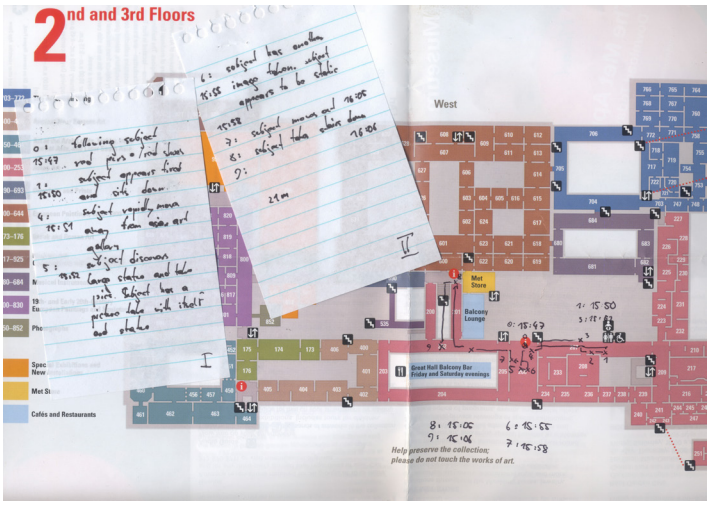
CULTURE FORAGING

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.

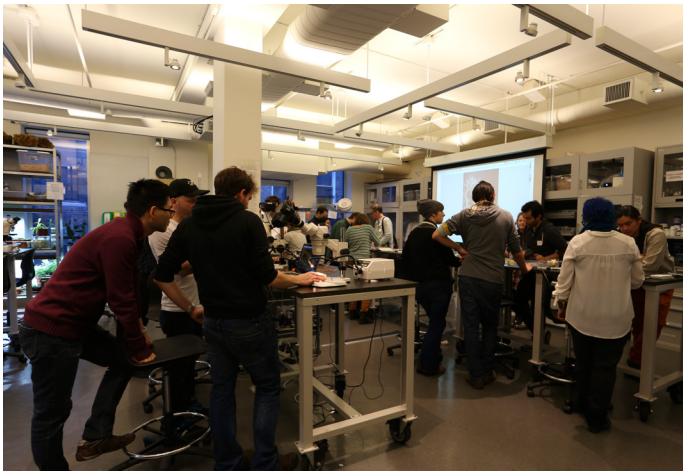
Slime molds have become notorious as organisms that can solve complicated labyrinths and find the shortest path between food sources. This is interesting to scientists and mathematicians as maze navigation can fall into the set of 'NP–Complete problems'—in layman's terms a set of problems that is characterized 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.

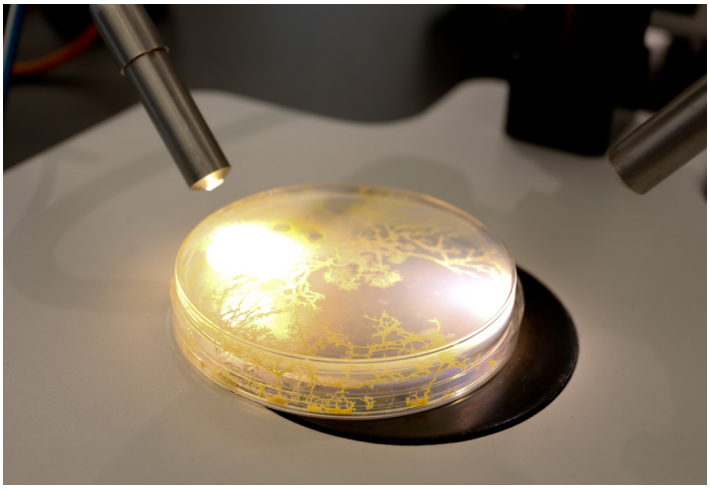
Crowd behavior is something we humans recognize, which made me wonder about the question of intersubjectivity—the amorphous zone where our respective worlds might overlap. The *Physarum* experiences its perceptual world; we experience ours. We experience *Physarum* experiencing its perceptual world, 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.*