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Biological Computation of Physarum

From DLA to spatial adaptive Voronoi

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Physarum polycephalum, also called slime mold or myxamoeba, has started attracting the attention of those architects, urban designers, and scholars, who work in experimental trans- and flexi-disciplines between architecture, computer sciences, biology, art, cognitive sciences or soft matter; disciplines that build on cybernetic principles. Slime mold is regarded as a bio-computer with intelligence embedded in its physical mechanisms. In its plasmodium stage, the single cell organism shows geometric, morphological and cognitive principles potentially relevant for future complexity in human-machines-networks (HMN) in architecture and urban design. The parametric bio-blob presents itself as a geometrically regulated graph structure-morphologically adaptive, logistically smart. It indicates cognitive goal-driven navigation and the ability to externally memorize (like ants). Physarum communicates with its environment. The paper introduces physarum polycephalum in the context of `digital architecture' as a biological computer for self-organizing 2D- to 4D-geometry generation.

Keywords: *generative geometry, bio-computation, Voronoi*

OVERVIEW

The introduction gives an introduction into the multicellular membrane organism. Part one contextualizes slime mold in the domain on network theory and presents lab-experiments of the physical organism. Part two defines the underlying logic of growth show the digitization of the self-organizing behavior using Python for Grasshopper. Here I am showing the morphological change from a branch-based geometry to a Voronoi-based geometry. The conclusion considers Physarum as liquid geometry computer and cybernetic disruptive bio-architectural device. This part describes the possibility for a transfer from bio-digital form-driven architecture to digital-biological behavior and material-driven architecture.

INTRODUCTION

Physarum polycephalum, literally is translated to 'multi-headed bubble'. Etymologically the term Physarum stems from the Greek word φυσα-physa, means Blasé, Pustel (Ger.) or bubble (Engl.) and shows similarities to the translation of bubble into Russian пузырь-puzir. (Kluge, 1967) It is a bright yellow amoeba-like, single organism with numerous nuclei. The Physarum's yellow color is the result of a pigment typology called Flavin. The tone can range from greenish yellow to bright yellow to deep orange; it is an indicator of the PH-value. (Seifriz and Zetzmann, 1935) (Kambly, 1939) The organism enlarges through foraging in search of nutrition. Its structure reveals three distinct geometric patterns: (a) on the edges Physarum polycephalum develops thin branches, searching their environment for food, b) distinct Voronoi pattern after a growth period (fig. 1a).Physarum is a system describing the characteristics of a liquid geometry computer-in conversation with its environment. Every system is goal driven-so is slime mold in conversation/interaction. The organisms goal is survival. It seeks achieving its goal by organizing the intake and distribution of nutrition through its entire body most efficiently for its capabilities. The molds behavior results in forming geometric patterns, namely branching as directed network graph, and Voronoi/Delaunay as an undirected network graph. While foraging the organism shows bulging blob-like (binary large object) geometric structure at the tips revealing a double-curved bulging droplet-like surface geometry Those clusters of blobs have an intricate topography at their edges demonstrating a landscape of regularly shaped and rounded hills. Figure 1b shows the rounded hills converged into sphere-like structures - geometrically akin to a meta-balls system. In the article "Intelligence: maze-solving by an amoeboid organism" on the smartness of the slime mold Physarum polycephalum, Nakagaki observed the intelligent decision-making behavior of the Physarum plasmodium. The organism was challenged with a maze-solving problem in order to reach the vital food, deposited on either entrance of the maze. The organism grew one connection on the shortest path possible between both sources, retracting all other links it had created prior to realizing that the food sources were connected. (Nakagaki et al., 2000) The project illustrated how a problem of computational complexity (here Botenproblem, travelling salesman problem (TSP)) could be managed by a living system without brain by applying biological intelligence. Since then there is an increase in experimentation with cellular slime mold in the fields of e.g., unconventional computing (Jones, 2015), art, network theory and urban planning and architecture. In 2016 Veloso and Krishmanturi utilized the slime mold algorithm for generating, designing and optimizing corridors in architectural spatial arrangements. The research links biological computation with circulation problems in buildings and urban spaces focusing on the development of networking methods, such as Adjacency Graph Selection (AGS) the authors Veloso and Krishmanturi developed. (Veloso, 2016)

PART 1: SLIME MOLD AS LIVING NETWORK THEORY

The following paragraph contextualizes slime mold in the domain of network theory and lab-experiments of the physical organism offers an insight into the organisms theoretical/algorithmic and parametric behavior and the corresponding physical appearance. In principle the growth is according to a morphing network graph - a mathematical logical model - consisting of vertices (nodes) and edges. The network graph of Physarum is a non-linear data structure. A non-linear data structure is a network graph in which a node is connected to more than one other node, meaning that several relations - in form of edges - provide the possibility for alternative flows on information. Non-linear data structures are more resistant then linear data structures since they have several ways of connection. Non-linear data structures show requisite variety (according to Ross Ashby the first law of cybernetics). It is one strategy of viability. (Ashby, 1957) (Heylighen, 2001) The growth behavior of slime mold shows different stages. Firstly, it grows from a central point equally and radially in all directions (fig. 2a). The centralized network changes after a short while to a hierarchical tree structure (branching) (fig. 2b). Depending on how nutrition sources are distributed, the graph remains undirected, or if an attractor (a food source) is added becomes directed (fig. 2c). Figure 2c shows two further phenomena: firstly, the foraging of branches once the food source had been inoculated; here to be seen at the perimeter of the

Figure 1
a: connection of 'attractors' b: foraging 'blobls'.

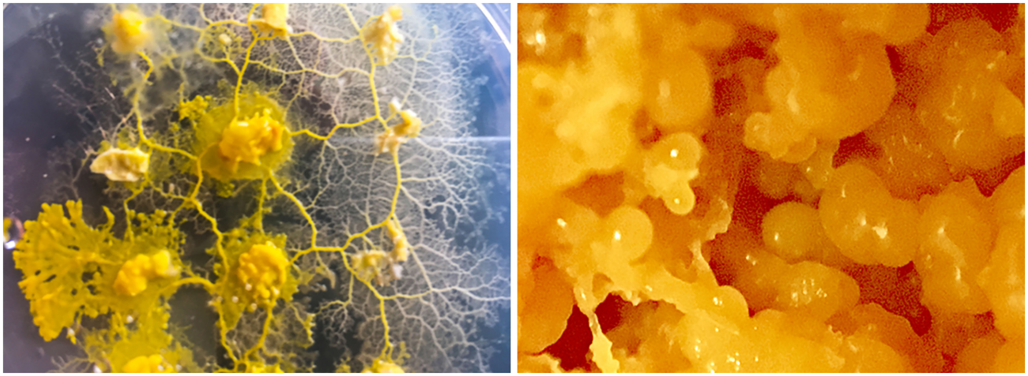
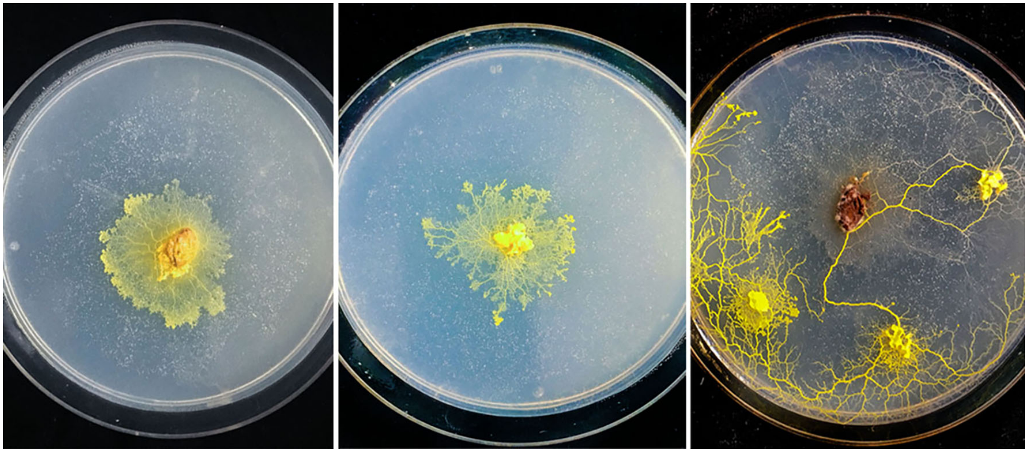


Figure 2
left a, centre b : Physarum undirected to directed growth; right c: 'external memory' substance in centre.



dish, and secondly, a visible substance in the center of the dish. This substance informs the organism, that it had been there and that there is no need to return to this space in the near future. The organism shows, similar to ants, a material intelligence, describes as 'external memory'. Once the organism has grown into a full Voronoi pattern, we can assume it is an undirected network graph. Apart from forming a morphing Voronoi (fig. 3a), that guarantees vitality throughout the system, the organism can create an intricate nest-like 4-dimensional complex structure (fig. 3b). Those structures are hardly visible by eye. They become visible through a 10-fold magnification. Figure 3b also shows the mold spanning diagonals from the horizontal surface if the Petri-dish's ground to the vertical surface of its rim. Other experiments show that the mold is also capable of building up vertical columns - presenting an intricate multiple folded and structurally ornate external membrane as shown in figure 3c.

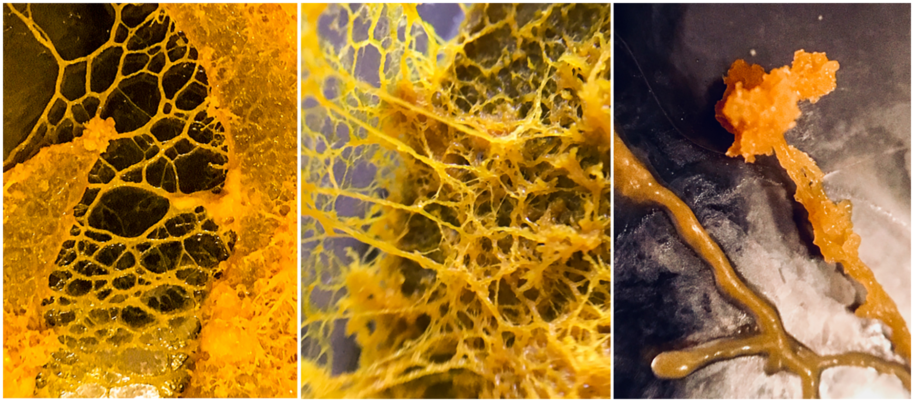


Figure 3
left a: Voronoi pattern; centre b: diagonal best-spanning; right c: vertical material growth.

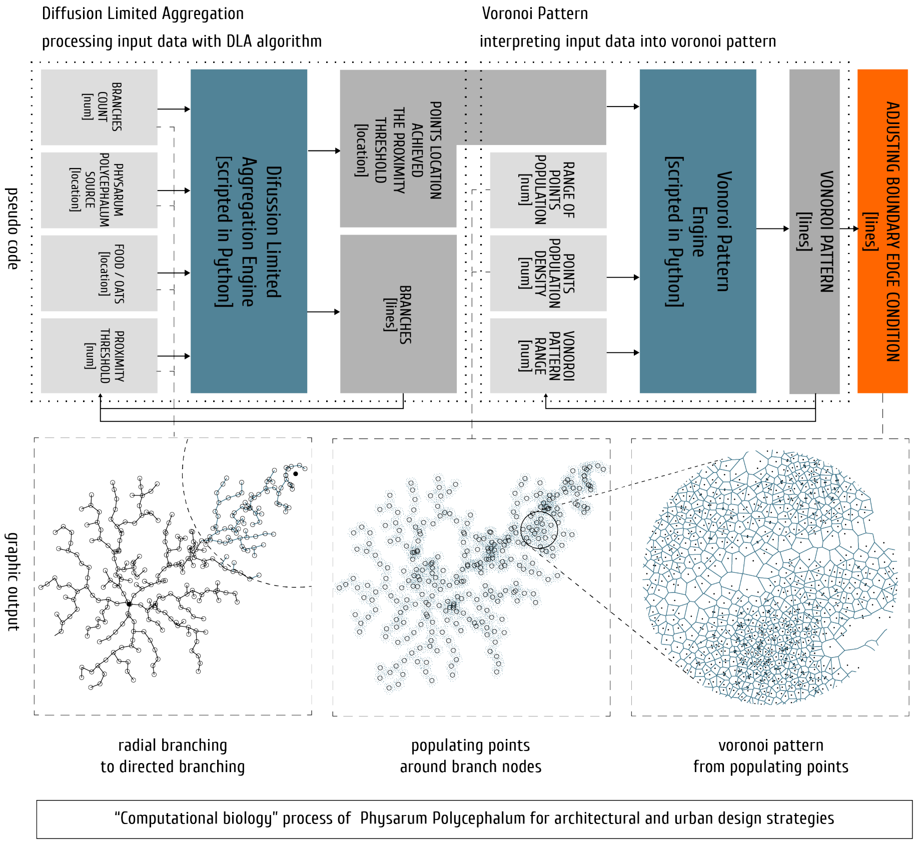
PART 2: THE DIGITAL SELF-ORGANIZING GROWTH OF PHYSARUM

from branching through DLA to Voronoi

In the early stage of its search for food the Physarum Polycephalum applies a branching algorithm; in a later stage the organism shows a Voronoi patterning algorithm. This can be achieved through the application of principles found in self-organizing multi-agent system, e.g., swarming or different types of cellular automata (CA). (Jones, 2016) Python for GH has been used to digitize the material structuring of Physarum in a 2-dimensional space. The emphasis on the research is to understand the growth pattern of the organism; thus, we have disregarded the tube-like physicality of the individual connecting 'arms' of the organism. We investigate, understand better and 'simulated' the underlying logic of growth and formal structuring. Hereby we prepared the expansion into 3- and 4-dimensional space, to be manifested further in the next step. Figure 4 show the diagram of digitizing the self-organizing behavior of Physarum Polycephalum using Python for Grasshopper in 2D.

In the research we tested diffusion-limited aggregation (DLA), one type of CA. It presents one way of creating the form of branching, also used here; this is achieved by agents 'randomly' wandering through space directed by Brownian motion and aggregating once close to each other. The aggregating behavior is the result of attraction of the agents to each other. In a multi-agent system simulation, the attraction force between agents can be varied. While the first phase (branching) - of forming the final geometric pattern (Voronoi) - is driven by attraction the second phase - forming the Voronoi pattern - is driven by the generation of repulsive fields; a method tested in the computer sciences in the past by Jeff Jones and Andrew Adamatzky. (Adamatzky, 2009) (Jones, 2015) We combined the two formation algorithms (fig. 4) in order to simulate the parametric dependencies in the geometry in either phase. Overlaying the two logics enables the morphological change from a branch-based geometry to a Voronoi-based geometry in one syntax. Figure 4 shows the input parameters of phase 01 (undirected): number of branches, a location of a starting point of growth, location of attractor points and a proximity threshold as circumference distance of the attraction point. Once an undirected network graph passes the proximity threshold it becomes a directed network graph (vector) foraging to the attraction point. At this moment operations of phase 02 - the Voronoi patterning - start. The diagram on the bottom right on figure 04 shows an enlarged region of the point population around branch nodes. Like on other scripts that are embedded in the environment Grasshopper, the expression can be controlled as an operation of post-algorithmic 'manual' adjustment. In the present script, we can globally change edge lengths and location of bifur-

Figure 4
“Computational biology” process of Phy.



cation points by changing the attraction circumference distance - a ‘manual’ post-algorithmic processing in the first phase. By moving an attraction point, the network morphs and the Voronoi pattern adjusts - a ‘manual’ post-algorithmic processing in the first phase. Naturally, the adjustment in phase 01 informs the output of phase 02.

CONCLUSION

Physarum polycephalum as liquid geometry computer and cybernetic disruptive bio-architectural device is one of the currently examined steps of a transfer from bio-digital form-driven architecture to digital-biological behavior and material driven architecture. The mold combines morphology, structure, infrastructure and metabolism; its algorithmic and parametric design strategies for architectural optimization and computational urban planning for a lean networked cognizant architecture. We suggest a transfer from the organism’s behavior in a global regional and local scale of architecture and urban design (fig 05). F05a and 05c show the primary branch which consolidates into the ‘shortest path’ and main infrastructural link forming the edges of each cell in the Voronoi typology. Computing the underlying logic of both phases of Physarum in combination with its cognitive intelligent capacity of externalizing memory suggests adaptivity based on environmental circumstances. We consider undirected and directed branching as well as the construction of infrastructure. Our introduction of the circumference as a changeable threshold is a crucial component. The organisms protoplasmic network paired with its structural abilities (fig. 03b, 03c), embedded intelligence of physically behaving towards growth and survival and learning/training capabilities suggests a novel field of interdisciplinary research for (a) bio-architectural design methods and strategies and (b) advanced computing material on a human scale for e.g., surfaces and building scale for e.g., construction or spatial changes according to the needs of the inhabiting actors. The outlook of this paper invites to a joined investigation into an extended digital theory in architecture through the parallels of biocomputers to the digitally networked space. The next stage may examine the mold's algorithmic and parametric design strategies intelligent cyber-physical building components made of soft and hard matter, partly regulated through liquid bio-computers based on learning and cognitive neural principals.

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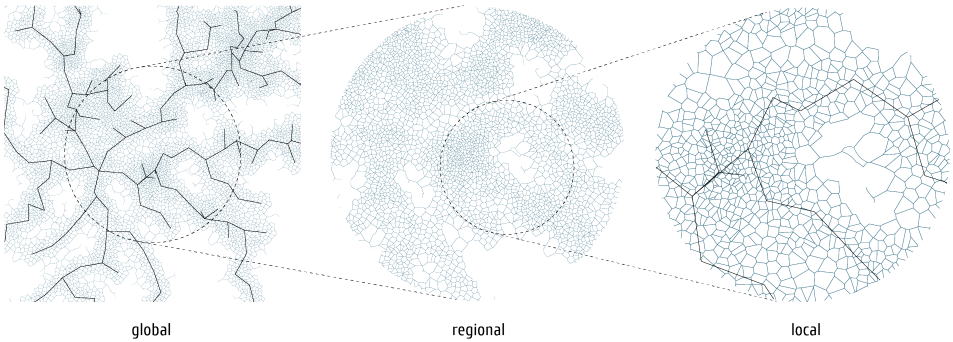

Figure 5
Global, regional and local morphology.