Beauty: A Machine-Microbial Artwork

Carlos Castellanos, Johnny Diblasi and Philippe Pasquier

April 30, 2021

Beauty: A Machine-Microbial Artwork *

Carlos Castellanos[1], Johnny DiBlasi[2], and Philippe Pasquier[3]

[1] Rochester Institute of Technology, Rochester, NY, USA
carlos.castellanos@rit.edu
[2] Iowa State university, Ames, IA, USA
jdiblasi@iastate.edu
[3] Simon Fraser University, Vancouver, BC, Canada
pasquier@sfu.ca

Abstract. We discuss *Beauty*, a hybrid biological-technological artwork, currently in development by Phylum, an experimental research collective an experimental research collective specializing in cultural production informed by the intersections of science, technology and the arts (and of which the authors are members of). The work is based upon an artificial intelligence agent that uses deep reinforcement learning to interact with alter cultures of pattern-forming social bacteria in order to make them more aesthetically pleasing.

Keywords: pattern-forming bacteria · deep reinforcement learning · computational aesthetic evaluation.

1 Introduction

We describe *Beauty*, a hybrid biological-technological artwork, currently in development by Phylum, an experimental research collective specializing in cultural production informed by the intersections of science, technology and the arts (and of which two of the authors are members). The work creates a situation where the fates of some contaminated soil and a group of bacterial cultures are determined by the whims of an artificial intelligence agent, which has an internal model of "beauty". The agent builds its model by observing the cooperative pattern-forming and swarming behaviours of selected bacterial species. It then attempts to modify the bacteria growth, both visually and spatially by introducing chemical attractants and repellents. As shown in Figure 1, cultures are placed under microscopes for observation and analysis by the agent. Images of their growth, movement and newly acquired synthetic abilities are captured using time-lapse microscopy. Growth patterns, colours and spatial dynamics are analysed by the agent to determine how well the colonies conform to its internal model of beauty. The more beautiful the growth patterns of the cultured bacteria appear to the agent the more of a remediating solution the soil receives and the more nutrients the bacterial cultures receive. It is known however, that these bacteria only

* Supported in part by Coalesce Center for Biological Arts, State University of New York at Buffalo, Rochester Institute of Technology and Iowa State University

produce their intricate patterns under environmental stressors such as lack of food and moisture. Thus, the agent also has to reduce nutrient levels and introduce stress-inducing chemicals (e.g. non-lethal concentrations of antibiotics) into the bacterial cultures. In addition, the bacteria will be genetically modified in a way that manipulates their stress-response genes to express the aforementioned "beauty enhancements". Thus in order to properly remediate the contaminated soil, the bacteria may have to starve themselves in order to look beautiful for the agent. The agent also expresses its "feelings" about this process via a series of evolving sound and visual patterns.

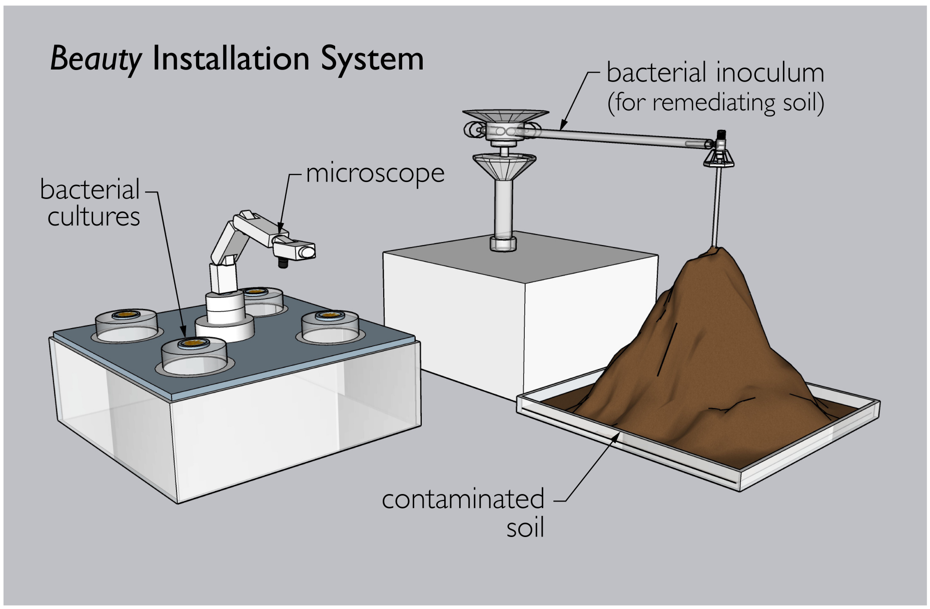

Fig. 1. Fig 1. *Beauty*, 2020, Phylum, microscope, robot arm, soil, Copyright by Phylum.

2 A Primer on Pattern-Forming Bacteria

Modern bacteriology abounds with examples of dynamic self-assembly and self-organization [7]. The focus of this project is on cooperative pattern-forming of bacterial colonies. These are characterized by the formation complex, often fractal-like, patterns that colonies develop in response to adverse growth conditions, such as lack of nutrients [2]. These occur most often in *Bacillus subtilis* and certain members of the genus *Paenibacillus* (such as *P. dendritiformis*, shown in Figure 2). While the aesthetic value of these patterns have not been studied in any significant way, they have nevertheless proven to be a source of curiosity and fascination for scientists and laypersons alike.

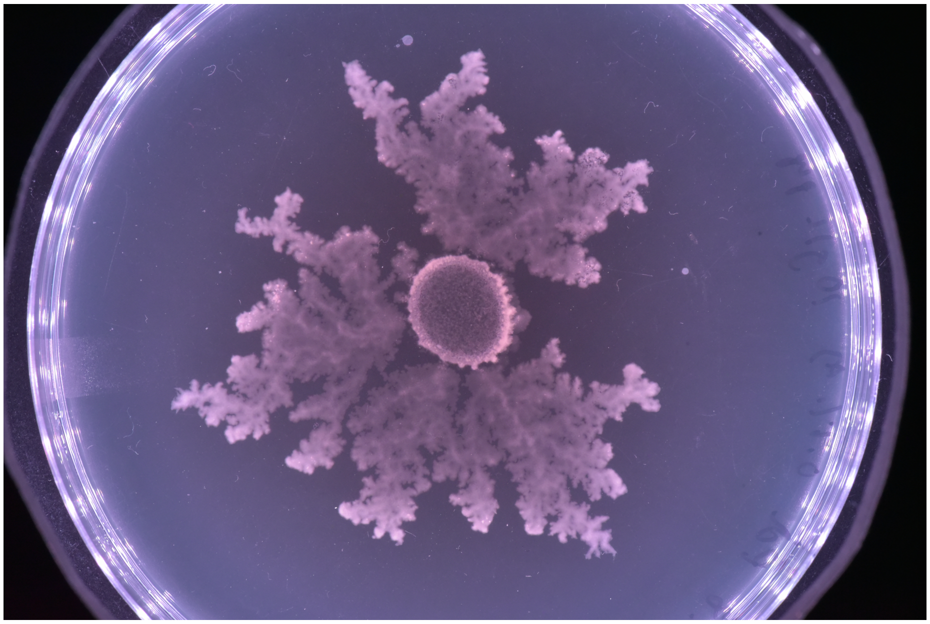

Fig. 2. Fig 2. A colony of Paenibacillus dendritiformis under dark-field illumination after approximately 48 hours of growth.

3 Agent Model

Our agent model is based upon the world model [5], a deep reinforcement learning model that generates simulated environmental states for the agent to adjust its policy (mappings of states to actions) before taking action in the real environment. A distinguishing feature of the world model when compared to other model-based RL approaches [6] is the ability to train an agent within its own internally generated model of the environment rather than the environment itself. In essence, the agent generates images of the environment and trains itself through experimentation within its own generative hallucinated dreams, rather than the actual environment. In our project, we are currently experimenting with extending the world model by adding a physics-based domain knowledge of the bacterial growth and an aesthetic evaluation model. This facilitates agent training and allows the agent to more reliably manipulate the bacterial colonies. In essence, enabling the agent to dream of other, more beautiful bacterial colonies and attempt to make those a reality. While we are currently testing our system with the "stock" world model, future iteration will include a physic-guided RNN [8] that uses the "communicating walkers" and lubricating bacteria models of bacterial growth and pattern-forming [3].

In addition, our research also involves the challenging task of developing computational aesthetic evaluation methods for the bacterial patterns. Computational aesthetic evaluation involves computers making normative judgements related to questions of beauty and taste in the arts [4]. This is a largely unsolved problem, with no agreed upon methods and metrics. We are currently exploring both the use of fractal dimensions – which have been shown to have some correlation to aesthetic preferences for chaotic patterns [1] – and conditioning our model on data sets of artworks that are considered "beautiful" (for example all of the paintings in the Louvre in Paris, or of people or things that are considered attractive or aesthetically pleasing in particular cultures).

4 Conclusions

This project addresses timely and relevant issues by establishing a unique interplay between "primitive" microorganisms, cultural notions of beauty and aesthetic judgement, the status and implications of intelligent machines and the impact of humans (and their technologies) on our ecology. In addition, while today all manner of microorganic labor is marshaled to produce products for humanity ranging from food to fuel to pharmaceuticals (not mention their use in cleaning up our environmental messes), we recognize these creatures as lively and dynamic, with agency and lifeworlds of their own. Thus the motivation for this work lies in creating an interface or window through which these organisms can convey their complexity and otherness using a language that can be understood by humans and the intelligent systems they create. We hope that this "creative misuse" of synthetic biology and AI will inspire new ways of looking at the relationship between humans, technology and the more than human world.

References

1. Aks, D.J., Sprott, J.C.: Quantifying Aesthetic Preference for Chaotic Patterns. Empirical Studies of the Arts **14**(1), 1–16 (1996)
2. Ben-Jacob, E.: From snowflake formation to growth of bacterial colonies II: Cooperative formation of complex colonial patterns. Contemporary Physics **38**(3), 205–241 (1997)
3. Cohen, I., Golding, I., Kozlovsky, Y., Ben-Jacob, E., Ron, I. G.: Continuous and discrete models of cooperation in complex bacterial colonies. Fractals **7**(3), 235–0247 (1999)
4. Galanter, P.: Computational Aesthetic Evaluation: Past and Future. In: McCormack, J., d'Inverno, M. (eds.) Computers and Creativity, pp. 255–293. Springer, Heidelberg (2012).
5. Ha, D., Schmidhuber, J.: World Models. arXiv:1803.10122 [cs, stat], http://arxiv.org/abs/1803.10122. (2018)
6. Plaat, A., Kosters, W., Preuss, M. Deep Model-Based Reinforcement Learning for High-Dimensional Problems, a Survey. arXiv:2008.05598 [cs], http://arxiv.org/abs/2008.05598. (2020)
7. Shapiro, J. A.: Thinking about Bacterial Populations as Multicellular Organisms. Annual Review of Microbiology **52**, 81–104 (1998)
8. Willard, J., Jia, X., Xu, S., Steinbach, M., Kumar, V. Integrating Physics-Based Modeling with Machine Learning: A Survey. arXiv:2003.04919 [physics, stat], http://arxiv.org/abs/2003.04919. (2020)