Beauty

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Abstract

We discuss *Beauty*, a machine-microbial artwork wherein a deep reinforcement learning agent alters cultures of pattern-forming bacteria in order to make them more "beautiful". The results of these actions determine the fates of both the bacteria and a contaminated soil ecology.

1 Introduction

Beauty is a machine-microbial 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 features a bio-driven artificial intelligence that remediates a contaminated soil ecology while generating an audio-visual composition in real-time. It creates a situation where the fates of the contaminated soil and a group of bacterial cultures are determined by the whims of a deep reinforcement learning agent with an internal model of "beauty". As shown in Figure 1 (a), the growth and movement of pattern-forming bacterial colonies (such as *Paenibacillus dendritiformis*, shown in Figure 1 (b)) are captured using time-lapse microscopy and sent to the agent. Our agent model is based upon the world model [5], a deep reinforcement learning model that generates simulated environmental states via a Variational Autoencoder and Recurrent Neural Network. Growth patterns and spatial dynamics are observed and analyzed 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 the remediating solution the soil receives and the more nutrients the bacterial cultures receive. It is known however, that these bacteria only produce their intricate patterns under environmental stressors such as lack of nutrients [2]. Thus the agent will also have to reduce nutrient levels and introduce stress-inducing chemicals, such as antibiotics, into the bacterial cultures. Thus in order to properly remediate the contaminated soil, the bacteria may have to starve themselves to look beautiful for the agent. The agent in a sense is acting as a kind of sculptor or film director, shaping the colonies according to the vagaries of its aesthetic inclination. The agent will also express its "feelings" about this process via a series of evolving sound and visual patterns.

2 Computational Aesthetic Evaluation

Part of our research 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

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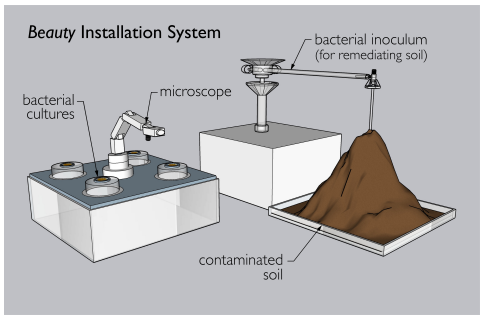
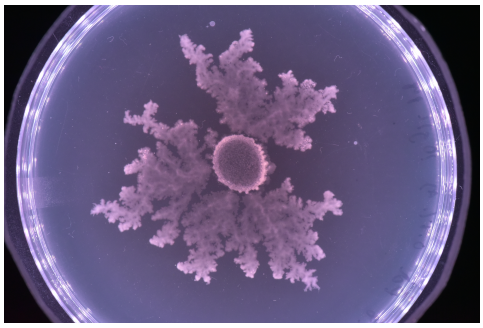


(a) Microscope, robot arm, soil. Copyright by Phylum



(b) A colony of *Paenibacillus dendritiformis* after approximately 48 hours of growth

Figure 1: *Beauty*, 2020-21, Phylum

problem, with no agreed upon methods and metrics. We have begun with a simple aesthetic evaluation model based upon subjective rankings of the images. To date we have experimented with two models. One is a ResNet50 classifier and the other a custom model that is not as complex. We found out that both the models perform similarly hence for now there is no real advantage to using a complex model like ResNet50. Our method is similar to that of [6]. A dataset of 147 bacterial images containing a numeric aesthetic ranking of each ranging from 0 to 100, with 0 the lowest and 100 the highest. These rankings were all performed by Castellanos, and thus represent his personal aesthetic preferences. Even with the relatively small dataset, the models manage to give us good accuracy (see the appendix for the confusion matrix of both models).

3 Future Work

We are currently experimenting with extending the world model by adding physics-based domain knowledge of the bacterial growth. Using a physics-guided RNN [7] based on a mathematical model of bacterial growth [3] should improve agent training. We are also 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 datasets of artworks that are considered beautiful (for example all of the paintings in the Louvre in Paris, or of people or objects that are considered attractive or aesthetically pleasing in particular cultures).

4 Conclusion

Beauty 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 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., AND SPROTT, J. C. Quantifying Aesthetic Preference for Chaotic Patterns. *Empirical Studies of the Arts 14*, 1 (Jan. 1996), 1–16. Publisher: SAGE Publications Inc.

[2] BEN-JACOB, E. From snowflake formation to growth of bacterial colonies ii: Cooperative formation of complex colonial patterns. *Contemporary Physics 38*, 3 (1997), 205–241.

[3] COHEN, I., GOLDING, I., KOZLOVSKY, Y., BEN-JACOB, E., AND RON, I. G. Continuous and discrete models of cooperation in complex bacterial colonies. *Fractals 07*, 03 (Sept. 1999), 235–247.

[4] GALANTER, P. Computational aesthetic evaluation: Past and future. In *Computers and Creativity*, J. McCormack and M. d' Inverno, Eds. Springer, Berlin, Heidelberg, 2012, pp. 255–293.

[5] HA, D., AND SCHMIDHUBER, J. Recurrent World Models Facilitate Policy Evolution. In *Advances in Neural Information Processing Systems 31* (Montreal, 2018), S. Bengio, H. Wallach, H. Larochelle, K. Grauman, N. Cesa-Bianchi, and R. Garnett, Eds., Curran Associates, Inc., pp. 2450–2462.

[6] MCCORMACK, J., AND LOMAS, A. Understanding Aesthetic Evaluation Using Deep Learning. In *Artificial Intelligence in Music, Sound, Art and Design* (Cham, 2020), J. Romero, A. Ekárt, T. Martins, and J. a. Correia, Eds., Lecture Notes in Computer Science, Springer International Publishing, pp. 118–133.

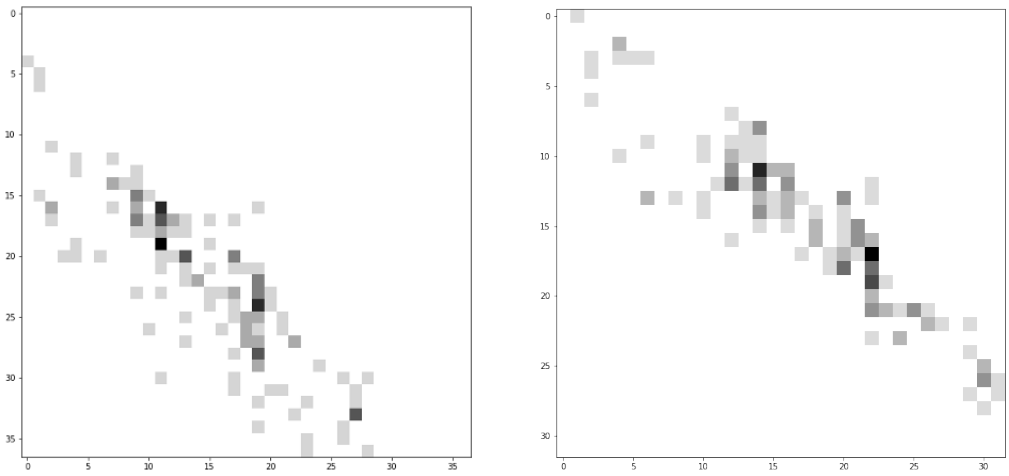
[7] WILLARD, J., JIA, X., XU, S., STEINBACH, M., AND KUMAR, V. Integrating Physics-Based Modeling with Machine Learning: A Survey. *arXiv:2003.04919 [physics, stat]* (July 2020). arXiv: 2003.04919.

A Appendix

Supplemental figures are included below. Code for this project is available at the following GitHub repositories:

- `https://github.com/CoEmergenceLab/WorldModel-VAE`
- `https://github.com/CoEmergenceLab/WorldModel-VAE-RNN`
- `https://github.com/CoEmergenceLab/BeautyRated`
- `https://github.com/CoEmergenceLab/Beauty-Robot`

Further project documentation is available at `https://ccastellanos.com/projects/beauty/`



(a) ResNet50 (b) Custom Model

Figure A.1: A confusion matrix of the ResNet50 model (a) and custom model (b). Both models give similar results but the custom model uses significantly less parameters, thus making it more desirable.

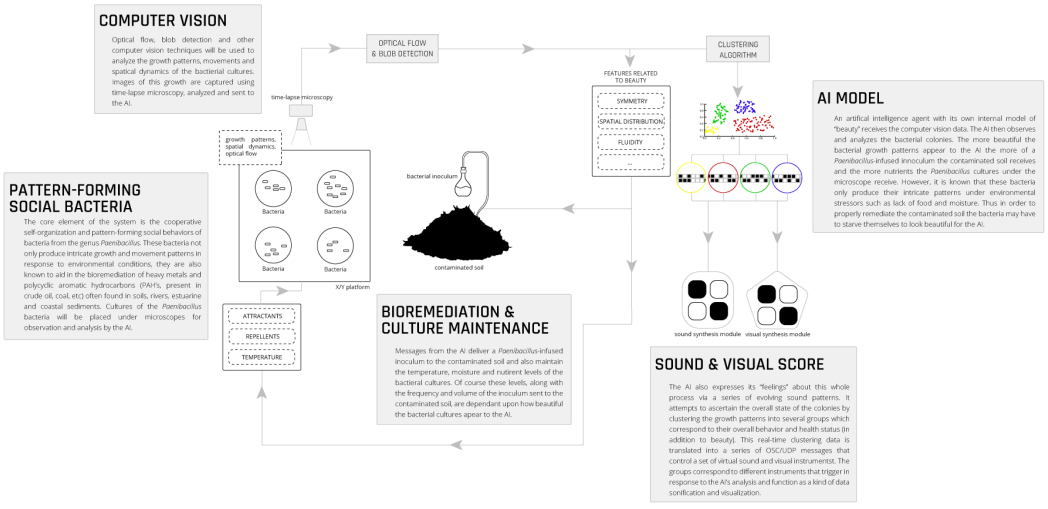


Figure A.2: Diagram of the *Beauty* system