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BEAUTY OF LIFE IN DYNAMICAL SYSTEMS: AN AESTHETIC VIEWPOINT OF LIFE

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ABSTRACT

Information plays a key role in life and complex biological systems. It is hypothesized that information processing capabilities distinguish life from other so-called non-living matter. Dynamical systems underlie and can be used to represent many complex life-like systems. Dynamical systems and information processing may be the hallmarks of life-like systems.

We combine dynamical systems with a computational framework to generate art. The framework can be used to generate aesthetically appealing forms of life-like systems. Our work suggests that we may need an "aesthetic sense" to recognize life we have never seen before.

This aesthetic view also allows us to appreciate the beauty of life-like systems, life-forms around us, and their intimate connections with dynamical systems. This perspective can give us a sense that every part of the Universe computes and that the entire Universe is alive and has intelligence. We hope this will give humanity a new sense of purpose, help us appreciate our place in the Universe and also give a renewed thrust to conservation efforts to save our planet.

KEY WORDS

life, dynamics, Belousov-Zhabotinsky, NetLogo

CLASSIFICATION

JEL: C65

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INTRODUCTION

Information plays a critical role in life and complex systems. Complex biological systems co-ordinate heterogeneous components in a decentralized fashion. How do these distributed and decentralized systems with billions of cells and components function? One key component is how these complex systems efficiently collect and process information.

It is hypothesized that information processing capabilities distinguish life from other so-called non-living matter [1]. Information processing is a key ingredient for life. Chemical reaction systems called reaction-diffusion systems have been studied for their complex properties for a long time. One example is the Belousov-Zhabotinsky (B-Z) reaction which is a chemical oscillator and displays complex properties reminiscent of life, Figure 1 [2, 3].

We hypothesize that carbon-based life forms are only one amongst a continuum of life-like systems that are possible in our Universe. Investigations into the role of computational substrates that allow information processing is important and could yield insights into:

1) novel non-carbon based computational substrates that may have "life-like" properties, and
2) how life may have actually originated from non-life on Earth.

Life may exist as a continuum between non-life and life and we may have to revise our notion of life and how common it is in the universe. Looking at life or life-like phenomena through the lens of information theory can yield a broader view of life. Information processing capabilities can distinguish life from other so-called non-living matter [1].

Information processing is one amongst many key ingredients for life. Chemical reaction systems called reaction-diffusion systems have been studied for their complex properties for a long time.

The science fiction writer Arthur C. Clarke once described a potential alternate form of life that arises on an ultra-cold planet [4]. He envisioned electrical currents and waves forming in a superconducting fluid of liquid Helium 3. The entire planet is barely above absolute zero, yet harbours an intelligence that uses these electrical currents to perform computation. Very little material transport occurs and most information processing happens using waves of electrical currents that propagate to form a planetary scale global "brain". This form of intelligent alien life stretches the boundary of what we currently call life. It may not be recognized as intelligent life, if we did encounter it, using the guidelines of carbon-based lifeforms we have observed on Earth.

TEACHING RESOURCES

This section presents teaching resources for high-school and undergraduate students. We assume that the students have a basic background and interest in science.

Our conception of life is shaped by what we see around us on Earth. What life forms might we expect to see on alien planets? Would they be carbon-based like us or can they be even more exotic? Answering questions like these means we have to come up with an objective definition of life.

Chemical reaction systems called reaction-diffusion systems have been studied for their complex properties for a long time. One example is the B-Z reaction which is a chemical oscillator and displays complex properties reminiscent of life, Figure 1 [1, 2]. The full model is available on the NetLOGO online platform [2, 5]. The parameters chosen for the simulation are also shown in Figure 1. The students can click on the setup button, play around with the sliders and set the parameters. They can then click on the go button. This will start the simulation. Simulation time is called ticks and is shown in the window in Figure 1.

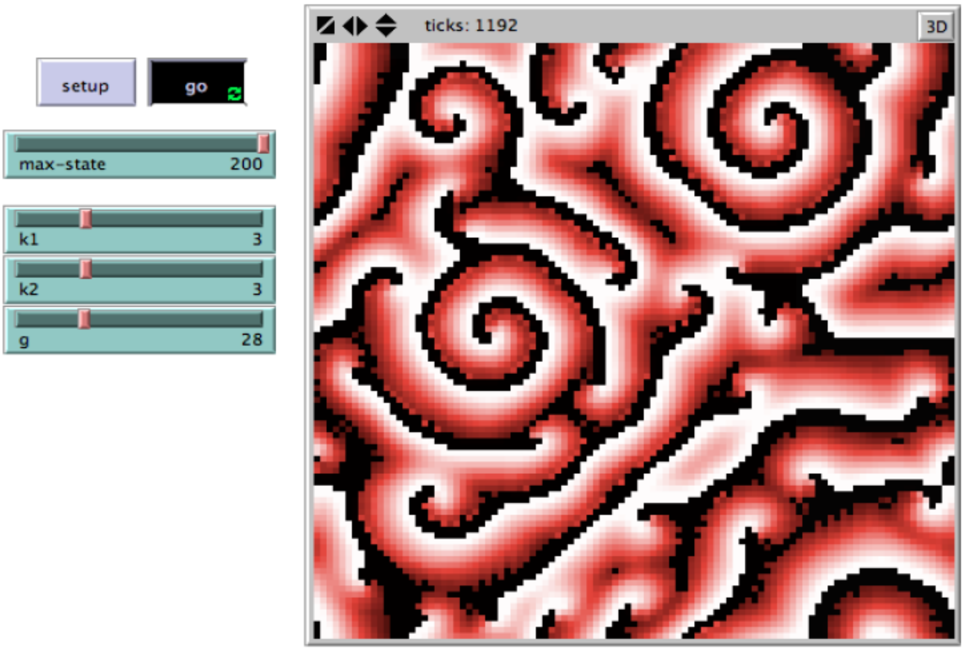

Figure 1. Screenshot from the NetLOGO simulation tool for the B-Z reaction showing wave like patterns that persist [6].

SOFTWARE RESOURCES FOR ACTIVITIES: INSTALLATION AND PREREQUISITES

We introduce some computational resources which can be used to create activities for students. These resources are available from the repository

https://github.com/neelsoumya/deep_dali.

This requires the Python programming language which can be installed from

https://www.python.org/downloads.

The dependencies can then be installed by typing the following at the command line:

pip install -r requirements.txt.

The NetLOGO language can then be installed from

https://ccl.northwestern.edu/netlogo/download.shtml.

Alternatively a version of NetLOGO that can be run from the web browser is available here:

http://netlogoweb.org.

As way of introduction, B-Z reaction displays complex properties and wave-like patterns reminiscent of life, Figure 2 [2, 3]. Students can generate this image by going to the following website which runs NetLOGO in the browser:

http://netlogoweb.org/launch#http://netlogoweb.org/assets/modelslib/Sample%20Models/Chemistry%20&%20Physics/Chemical%20Reactions/B-Z%20Reaction.nlogo.

They can click on the setup button and then the go button. This will start the simulation of the B-Z model. The simulation will yield myriad beautiful patterns. Once the students observe a pattern they like, they can pause the simulation by clicking on the go button. They can then take a screenshot of the pattern and save it on their computer (say as *simulation.jpg*). The image of this reaction-diffusion system can then be modified using a deep-learning algorithm (Google Deepdream) [7]. The deep learning algorithm modifies the image and creates a new image with dream-like qualities. A sample of such a modified image is depicted in Figure 3.

The deep learning 'dreaming' program is available at:

https://github.com/neelsoumya/deep_dali/blob/main/deep_dream.py.

The student can download the full code repository

https://github.com/neelsoumya/deep_dali.

The deep learning program can be executed by running the following at the command line:

python3 deep_dream.py simulation.jpg result_dream.

The new modified picture will be saved as *result_dream.jpg*. The image has a dream-like quality and emphasizes the beauty in life and in dynamical systems. It points to the computational origins of beauty in life itself. Our framework forms new representations of potential life-like systems. Artificial Intelligence (AI) coupled to dynamical systems can be used to form new representations of life-like systems that may possibly exist somewhere in our Universe. More examples on computational art for dynamical systems can be found in the following repository:

https://github.com/neelsoumya/deep_dali.

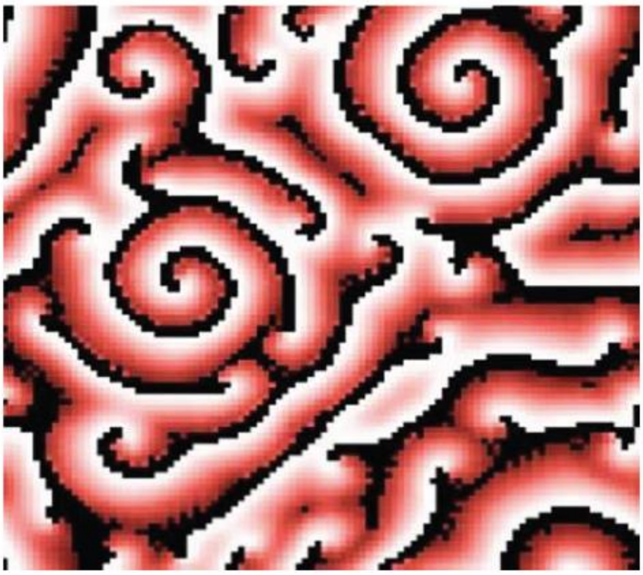

Figure 2. Screenshot from the NetLOGO simulation tool for the B-Z reaction showing wave like patterns that persist [2, 3].

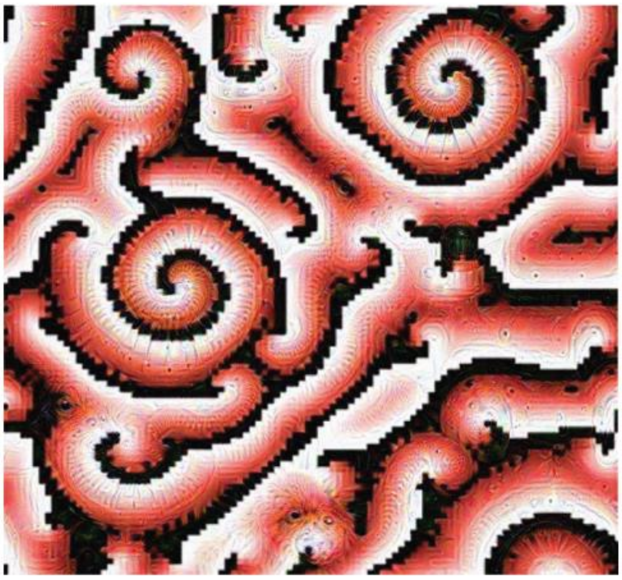

Figure 3. The image of a reaction-diffusion system modified using a deep-learning algorithm.

CORE ACTIVITIES

We outline some core activities in this section. Not all parameters in the B-Z reaction system will lead to patterns. An example is shown in Figure 4. After 446 time steps, one can observe no patterns at all. This suggests that life or life-like systems are very fragile. We note that since the simulation is stochastic, you will not get the same result every time, even if you run it with the same parameters.

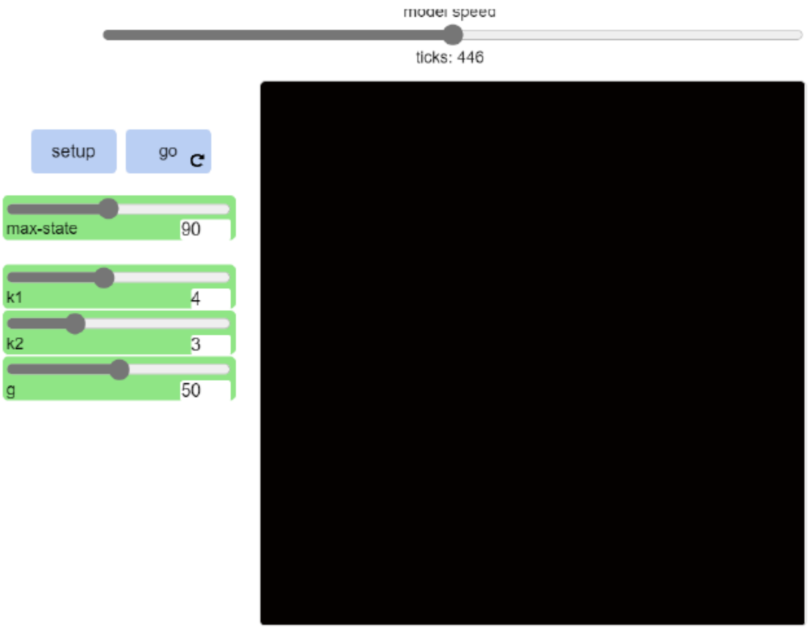

Figure 4. Screenshot from the NetLOGO simulation tool for the B-Z reaction showing no patterns after the simulator is run for 446 time steps [6].

We encourage students to play around with the parameters by moving the sliders. Some parameters can also lead to persistent but very simple patterns, Figure 5.

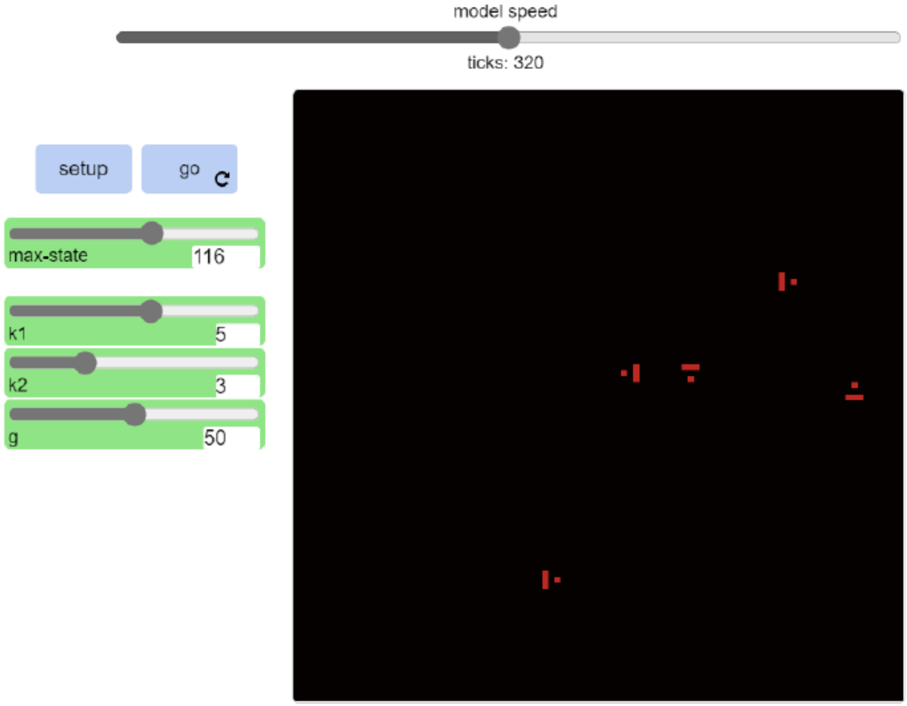

Figure 5. Screenshot from the NetLOGO simulation tool for the B-Z reaction showing a pattern that is very simple but still persists over time [6].

ACTIVITIES ON DYNAMICAL SYSTEMS

Another activity is thinking about creation and destruction of life as shown in a simple model of a forest fire. This can be simulated on the website https://sandspiel.club. A forest fire model is a very simple way to visualize and think about complex dynamics, and reflect on how life is about creation and destruction. We now outline the steps of how students can use this website to create simulations. Once the webpage is opened, students will see the screen shown in Figure 6.

Figure 6. Screenshot of the first step of a forest fire model simulated on https://sandspiel.club. This is the opening page and initial step.

The next step is to add seeds. This can be done by clicking on the button labelled Seed and then clicking on the grey simulation area shown in Figure 7.

Figure 7. Screenshot of the second step of a forest fire model simulated on https://sandspiel.club. The student has to click on the button labelled Seed and then click on the grey simulation area in the center of the screen.

The next step is to add some water, which can be done by clicking on the button labelled Water and then clicking on the grey simulation area in the center of the screen. Alternate between adding seeds and water and the plants will begin growing. A snapshot of this simulation is shown in Figure 8.

Figure 8. Screenshot of the third step of a forest fire model simulated on https://sandspiel.club. This shows the plants growing progressively as seed and water are added.

Once the plants have grown for some time, the student can add some fire by clicking on the button labelled Fire and then clicking on a plant in the grey simulation area. This would set fire to the plants and the fire would rapidly spread. A screenshot of a sample simulation is shown in Figure 9. This simulation depicts the creation and destruction of life.

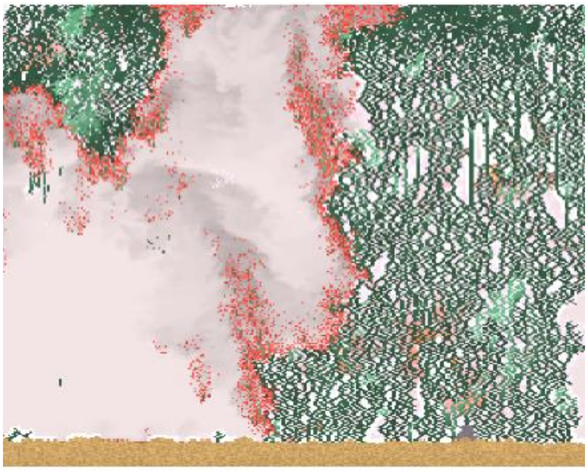

Figure 9. Screenshot of a forest fire model simulated on https://sandspiel.club. The simulation is meant to depict the creation and destruction of life.

Additional activities for students: Students can now think of other ways to grow plants. What would happen if you added some fungus and mite by clicking on the buttons labelled Fungus and Mite. What would happen if you added some oil (play around with the Oil button)? Team up with your best friend and play with these simulations on two different computers. Ask your friend to follow the same steps as you do. Can you try to replicate the simulation on your friend's computer? If not, why do you think the simulations are different on these two computers, even though you followed the same steps? Students can then modify the picture (Fig, 9) using the deep learning ‘dreaming’ program. The program is available at:

https://github.com/neelsoumya/deep_dali/blob/main/deep_dream.py.

The student can download the full code repository

https://github.com/neelsoumya/deep_dali,

and then install python on a laptop. The dependencies can be installed by typing the following command at the command line:

pip install –r requirements.txt.

The deep learning program can be executed by running the following command:

python3 deep_dream.py life_creation_destruction.jpg result,

where life_creation_destruction.jpg is the name of the picture. The program will produce a modified picture named *result.jpg*. This picture is shown in Figure 10.

Yet another activity is described further in the text. The students can take a picture on their phone (for example, see Figure 11) and then modify it using the deep learning computer program. This picture can then be modified using the deep learning algorithm, Figure 12.

REFLECTION ACTIVITIES AND SUMMARY

Here we outline additional activities that can be arranged for school students who do not have sufficient background in science or mathematics.

ACTIVITIES

Students can start by listening to the short story Crusade by Arthur C. Clarke which discusses an alternate life form. An audio rendition is available here:

https://www.youtube.com/watch?v=Li0TnrRTmM8.

They can then listen to a short presentation on how this alternative view can tell us what can kind of life forms can exist in the Universe:

https://youtu.be/jDIt60LVyWY?t=76.

For school students who may not have enough scientific background, a very simple lay summary is given below. This can be read and then discussed by students in small groups. They can then draw a diagram of what kind of life they think we can expect to find elsewhere in the Universe.

LAY SUMMARY

What kind of life forms can we expect to find in distant planets? We always talk about life as we know it. But what about life as we do not know it? Hence the presentation outlined above is titled “Life as we do not know it”.

Life forms on earth are carbon based. It thrives on air, water, minerals and carbon in temperate conditions. This form of life consumes energy for its sustenance. Is it possible to have life forms in extreme cold conditions say –270 ˚C, without any air or water? We propose that life-like activity is possible in such conditions.

This life-form, however may be very different and hence is the title “Life as we do not know it”. In extreme cold conditions in some distant planet without air, water, sunshine, carbon and such other earthly materials, life-like activity is possible which consumes very little or no energy at all. Helium can exhibit life-like properties in extreme cold conditions in liquid form.

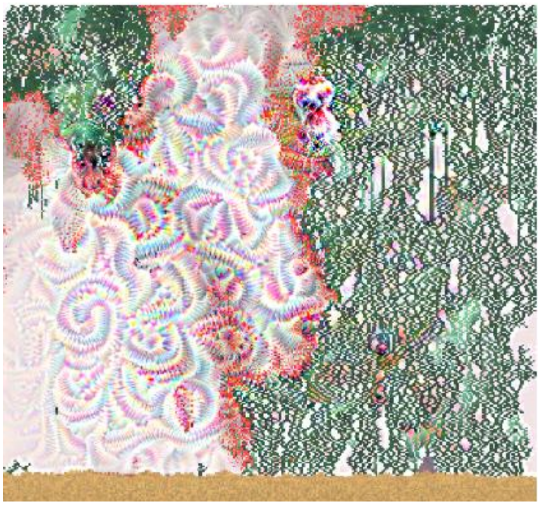

Figure 10. Screenshot of a forest fire model simulated on https://sandspiel.club modified with a deep learning dreaming program. The picture is meant to depict the creation and destruction of life.

Figure 11. An example picture taken using a smartphone. This is a picture of a sunset in Kolkata.

Figure 12. An example of a picture take using a smartphone and modified using a deep learning dreaming program.

Life-forms essentially should have the following:

1) Memory
2) Basic "intelligence" to process information
3) "Sense" external stimulus and act.

These features can be presented in the form of a mathematical model. In any rate, life in other planets is still a mystery.

SUMMARY OF LEARNING ACTIVITIES

We summarise some of the learning activities in this section. These activities would be appropriate for high school students or those studying for an undergraduate degree.

1) Warm-up questions.
   a) How might one define life?
   b) How might we recognize life that is completely "alien" to us?
   c) Does life need to be carbon-based?
   d) How do movies bias our conception of alien life-forms (do they have to be little green men?)
   e) How would you recognize life if it does not fit the definition of life we have seen on Earth?
2) Demonstration of software. Download the NetLOGO software [1] and experiment with the B-Z model. For what parameters do you observe the emergence of "interesting" patterns?
   a) Is this life-like?
   b) Would you call this life if you saw it on another planet?
   c) Peer-discussion and take feedback.
3) Watch the short story *Crusade* by Arthur C. Clarke describing a potential alternate form of life that arises from electrical currents and waves in a superconducting fluid [4].
4) Read the paper on a computational theory of the value of information in life [3].
5) Look at the video of waves propagating in a cell visualized using a powerful microscope [8]. Do you see similarities to the waves seen in the B-Z model?
6) Discussion. What did you learn from these papers?
7) Register on SAGANet (http://www.SAGANet.org) to join a community of people interested in questions around origins of life and astrobiology. Contribute to a discussion forum on SAGANet.
8) Writing task and group presentation. Have a discussion on what is life and how might you recognize it, if you were to find it in another part of the Universe. Write up your ideas in 2 pages and make a 5 minute presentation to your class on this.

EVALUATION

Here we present a rubric for how the class performance can be evaluated by the instructor or peers. These evaluations are suitable for high school students or undergraduates.

1.) Delivery of presentation
   a) Was the presentation on topic?
   b) Were the main ideas clearly communicated?
2.) Organization and format of write-up
   a) Does the write-up have a good introduction?
   b) Is it properly formatted?
   c) Are there any grammatical errors?
   d) Does the write-up have a conclusion?
3.) Originality of content

   a) Was the content original?
   b) Did the students make an effort to develop new ideas?

4.) Analysis of literature review

   a) Did the group assimilate the findings of the background reading into the write-up and presentation?

DISCUSSION

This work emphasizes the beauty of mathematics and dynamical systems especially in questions around origins of life. Our conception of life is shaped by what we see around us on Earth. What life forms might we expect to see on alien planets? Would they be carbon-based like us or can they be even more exotic? Answering questions like these means we must come up with an objective definition of life. It is hypothesized that an objective definition of life is that it should be capable of information processing and computing [1]. Our work also suggests that we may need an "aesthetic sense" to recognize life we have never seen before. Such aesthetic versions of life-like systems can be generated using the computational framework presented here. Life on other worlds may have been initiated and evolved very differently from what we are accustomed to seeing on Earth. For example, alien life may not even be carbon-based. We may need to look at life through a new lens to recognize life-like systems on other worlds. Our computational framework combines dynamical systems with deep learning to generate novel and aesthetically appealing forms of life-like systems. These potentially life-like systems can conceivably be present somewhere in our Universe. They can even broaden the search horizons beyond current searches for carbon-based lifeforms within the habitable zones of sun-like stellar systems. This aesthetic view also allows us to appreciate the beauty of life, life-forms around us, and their intimate connections with dynamical systems. This perspective can give us a sense that every part of the Universe computes and that the entire Universe is alive and has intelligence. We hope this will give humanity a new sense of purpose, help us appreciate our place in the Universe and also give a renewed thrust to conservation efforts to save our planet. Our work is also an example of how computational art can be created using empathetic Artificial Intelligence and dynamical systems. Such forms of art can be used to educate the general public about the benefits of AI and bridge the gap between lay audiences, artists and computer scientists. The general public, artists and computational scientists can come together to co-create computational life-like systems using AI. This will also allow us to value and appreciate life on Earth and how precious it is. Dynamical systems are general and powerful mathematical representations of our Universe. They can represent diverse complex systems ranging from intra-cellular regulatory networks to global scale models of how scientists collaborate with each other. We posit that dynamical systems underlie much of our Universe and we hypothesize that they form the basis of computation, life, intelligence and consciousness in our Universe [9].

CONCLUSION

In conclusion, we present teaching resources for school and university students. We hope our work will help popularize a computational view of life and educate students on how arts and mathematics can be unified. It will hopefully also instill an aesthetic sense of life in future scientists. We anticipate that our teaching resources may be especially useful in developing nations that are investing in science education. We hope our resources can be used to teach students in low and medium income countries. The only requirements are a laptop, desktop or smartphone with an internet connection. This work started with a science fiction story. We want to end with a question: what if someday we journey to the stars and we do find life. What if we fail to recognise it? What kind of metrics and objective criteria should we have for life or life as we do not know it? Only by educating the next generation of students can we keep an open mind about life elsewhere in the Universe and try to creatively reimagine what kinds of life can exist. An aesthetic sense of life will help in this reimagination of life or life-like forms that can exist elsewhere in the Universe. It will also allow us to better appreciate life on Earth.

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