Patterned Growth in Extreme Environments

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***Abstract*—In the search for life on Mars and other extraterrestrial bodies, one of the biggest problems facing us is, how do we recognize life or the remains of ancient life when we find it? We will need to recognize residual patterns left by life. One approach to recognizing these kinds of patterns is look at patterns created and left by life in extreme environments here on Earth.**

I. INTRODUCTION

A key aspect of planning a space mission, is to set scientific mission objectives, with the ability to adapt them based on observations and mission situations. The search for extraterrestrial life is a major scientific objective, but the exact nature of that life and how to confirm it is a major debate. We use life in extreme environments on Earth as analogs for the kinds of life that we could encounter in space. In resource limited environments, organisms grow in patterns that are self-enforcing and exhibit hysteresis, which can be used to recognize them and their fossils at a distance. Particularly on Mars, as the environment became less hospitable, extremophiles similar to Earth's were likely the last to survive, and should be the easiest to find. Among the techniques that have been used to model these patterns are evolutionarily stable strategies in game theory and differential equations.

While good results have been generated using differential equations, they require tuning of the parameters and experience in mathematical and numerical techniques to obtain valid results. In this work we developed cellular automata that produce similar predictions to the differential equation models, while preserving the rapid modeling and hypothesis testing of cellular automata. Our method for deriving rules for cellular automata from observed data in organism growth patterns accounts for soil nutrients, water, root growth patterns, and geology allowing scientists to easily examine the effects of modifying conditions without damaging the environment. We apply this model to identify factors affecting patterning with respect to growth, die-out, and stabilization in extreme environments. We compare the results of our model with biovermiculation microbial mats growth in acid caves, and cyanobacteria growth in Zzyzx, CA. These models could be used to rapidly check data from space missions to rate the potential of various locations of containing life or fossils.

II. BACKGROUND

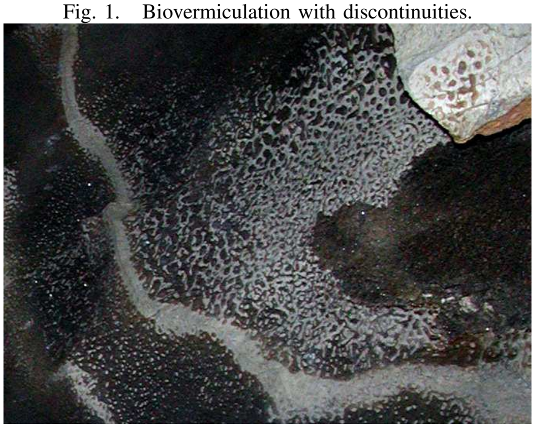
In the 1940s, John von Neumann developed the first cellular automata, while working on the self-replicating systems problem. In 1970, John Conway developed his Game of Life, a two dimensional cellular automaton that exhibited aspects of both order and randomness. In 1983, Stephen Wolfram published the first of many papers on cellular automata. His research into this area of mathematics culminated in 2002 with the publication of his book, A New Kind of Science.

A cellular automaton (CA) is a computational model that is discrete in both space and time. Essentially we divide space into boxes called cells, and only calculate their values at discrete time using a set of fixed rules. A state could represent anything, and in our case it represents the amount of water, nutrients and the biomass. The rules describe how the organism grows or dies in the presence of the water, nutrients and competition from other organisms. CA rules are not usually expressed as formulas, rather they are visual, such as drawing pictures of the neighboring cells and then labeling the next state. Cellular automata have been used to study growth and patterns in forests, arid desert environments, preditor-prey problems, and sea shells. It has also been used to study areas as diverse as epidemiology and linguistics.

III. EXTREMOPHILES

Extremophiles form patterns based on their own biology and the environmental conditions they exist in. The CA models are adapted to the biological and geological conditions found on Earth that are most likely to match those on Mars. Cyanobacteria and biovermiculations have been identified as

Fig. 1. Biovermiculation with discontinuities.



part of our work on NASA’s Spaceward Bound as likely to be similar to life on Mars.

Cyanobacteria are aquatic, photosynthetic bacteria and are notable for many reasons, including being the oldest fossils, the original producers of atmospheric oxygen, the source of much of our oil, and an ability to grow in extreme environments (including Antarctica). The cyanobacteria in Zzyzx are fossils, but preserve the structured growth we are considering. Given their pivotal and early role on the Earth, similar organisms are conceivable on Mars, and their easy identification is important for biological objectives on Mars.

Biovermiculations are microbial mats composed of bacteria, extracellular polysaccharide slime, embedded clay and other particles, in situ precipitated minerals (e.g. sulfur and gypsum), and even some small invertebrates like mites and nematodes. Biovermiculations exist in a wide variety of chemical and physical subsurface settings including sulfuric acid caves, mines, carbonate caves, lavatubes, and even Mayan ruins. Lavatubes have been identified on Mars, and more recently confirmed in a more elaborate study. Mechanisms to create solutional caves in evaporite mineral deposits on Mars have also been proposed. Such potential subsurface habitats could conceivably house or have housed microbial populations on Mars and left traces similar to those found in geomicrobiological communities in Earth’s subsurface, and thus provide the best opportunity to find life on Mars. Figures 1 and 2 show how biovermiculations can be simulated by a CA.

IV. CONCLUSIONS AND FUTURE WORK

The patterns of microbial extremophile growth, developed using cellular automata, can provide starting templates for the types of patterns we may see in lavatubes and caves on Mars. These patterns could provide indicators of life similar to the patterns that indicated water flow and possible “ponds” on the surface of Mars. These templates and the ability to rapidly identify high probability areas for detecting life will be vital to planning future Mars missions.

Fig. 2. Simulated biovermiculation growth