PATTERNED EXTREMOPHILES. K. E. Schubert[1], E. Gomez[1], J. Curnutt[1], and P. J. Boston[2] , [1]School of Computer Science and Engineering, California State University, San Bernardino, 5500 University Parkway, San Bernardino, CA 92407; keith@r2labs.org [2]Earth & Environ. Sci. Dept., New Mexico Institute of Mining & Technology, Socorro, NM 87801.

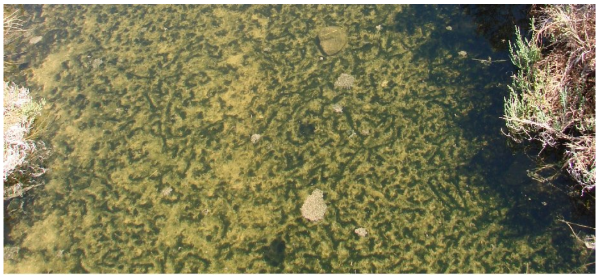

Figure 1:Patterning in Salt Creek, Death Valley.

Search for Patterns of Life: As resources become scarce, lifeforms adapt by growing in patterns that help them optimize their access to resources. From algae in Salt Creek, Death Valley, CA (Fig. 1), to soil crusts near Baker, CA (Fig. 2), to geometrically elaborate biomats on cave walls (Fig. 3) life in extreme environments frequently does not exhibit a solid mat of growth, but rather forms exotic patterns ranging from lines to circles, and harder to characterize amorphous patterns [1]. Similar patterns are seen in desert grasses around the world, and even in microbial mats in caves, (Fig. 3). Fortunately, such patterns often lithify and persist past the active growing phase of a community especially in microbial communities within caves. On any planet which had extant life at one point in its history, but now may have only scarce or fossil life, life probably has exhibited patterned growth. This implies that a reasonable search for life on other planets should involve looking for patterned growth in places where some type of life might still be holding on, or looking for fossilized patterns to find where life once lived [2].

If this was all that patterned growth was useful for, then it would be of limited utility, however the patterns themselves also tell us about the structure and resource conditions of the environment when the life was actively growing. This is important for understanding the overall conditions on the planet (or ancient time period on an earlier Earth), and thus can be used to make predictions of where else life might be found. On our own world, these patterns can serve as a barometer of past climate, indicators of prior environmental conditions when such biopatterns were formed, and can teach us about the fundamental energetics and ecology of microbial communities.

Figure 2: Patterned soil crust east of Baker, CA, courtesy Geoffrey Payton.

Figure 3: Figure 3: Regrowth experiment, courtesy Loise Hose, showing pattern variation from April 1999 to September 2003 in microbial mats on the walls of Cueva de Villa Luz, Tabasco, Mexico.

Cellular Automata Models: To describe, model, and extract system understanding, we utilize cellular automata. This is a model consisting of a grid of cells that can take on discrete values. Rules for how the cell values change are specified by the sum of all the cell values in some neighborhood. Cellular automata have been shown to be Turing complete, which means they can generate anything a computer can. This ensures that the approach is as general as any other modeling system. Specifically, we have used a system where cells could either be alive (1) or dead (0). The sum of all the neighbors within three cells of a cell is used as an index to a rule book, that specifies if that central cell will grow, die, or stay the same during the next time period. This summation and rule lookup process is done for every cell, at each time interval. The sum can vary from 0 to 49, which quantifies how dense the life is in that area. Zero is empty and 49 is full. Most rules were left as *stay-the-same*, including both 0 and 49, which must be left at *stay-the-same* for stability.

We have noted that in many natural systems there tends to be low density (sparse) regions, where only a few isolated organisms or small colonies exist, and high density areas (dense), where a solid mat is only broken up by isolated holes. These are generated by potential *wells*: the less dense area experiences net growth and the more dense area experiences net death. The growth rules in the less dense area thus increases the density towards the death rules in the more dense area, generating a relatively stable pattern with a density around the middle of each *well*.

Most patterns are composed of a series of wells in different regions, and their effect can be directly explained. For example:

1) A well in a low density region tends to cause the pattern to spread across the field and is thus necessary for life to perpetuate itself. This is almost certain to be the case in any system, as without it, it is unlikely that a community would have enough members to survive.

2) A well in a high density region tends to prevent growth from making a complete coverage of the field, and thus keeps the community from using up scarce resources too fast. The "holes" in the pattern move, providing for a natural equivalent of crop rotation.

3) A well in the middle densities allows a mechanism for smooth transition between the high and low density wells, thus allowing organisms to adapt to a changing environment and depleting resources without changing the fundamental strategy (the rules).

Pattern Simulation: To simulate the soil crusts found in the Mojave (Fig. 2) or cave wall patterns (Fig. 3), we needed a set of rules that could explain the wide sparse areas with widely varying growth patch sizes and very dense regions, which had more consistent hole sizes. This was handled by making the low density well have a relatively wide region of *stay-the-same* rules between growth and death. For instance, in Figure 4, the well rule was *grow* (1- 3) and *die* (8-12), leaving the wide region of 4-7 as *stay-the-same*. The high density well was located at *grow* (34- 38) and *die* (41-44), and thus had half the size of the bottom of the well and a slightly wider grow region to keep the edges sharp. The middle or transition well, was located at *grow* (25-27) and *die* (28-29). Notice it does not have any bottom to speak of, which encourages the communities to "bounce out" of the well. In other words, it is easier to overshoot either the death rules (if from a growth rule) or the growth rules (if from a death rule) and transition to the next well above or below in density. The lower end of the transition well was chosen to account for two of the low density spots getting close enough and merging, but not to allow one community to grow on its own. The result is a good approximation of the real soil crusts found in Figure 2. In Figure 4, green means *live*, brown indicates *dead*. Yellow in the rules means *stay-the-same*. The rules appear graphically on the left hand side from lowest density on the bottom to highest density on top

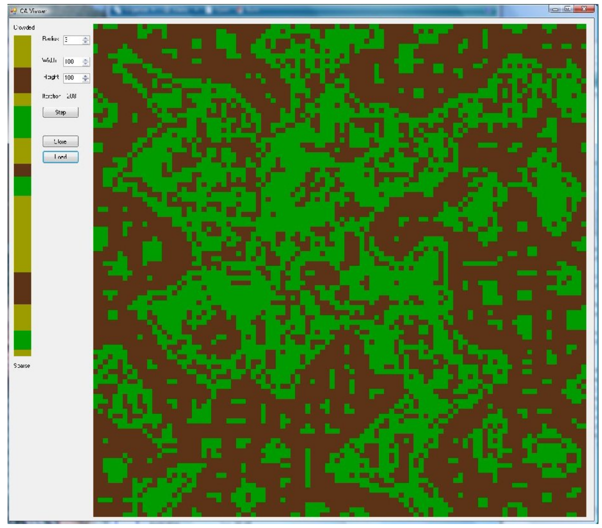

Figure 4: Simulation of cellular automaton with rule-set consisting of three "wells".

Conclusions: The cellular automata approach to biopatterning is of potentially great utility for the identification of possible biomarkers in extraterrestrial settings and in Earth's ancient rock record. The fundamental ecological and energetic drivers that make such biopatterning successful is likely to be a broadly distributed property of life, irrespective of particulars of chemistry, genetics, or other biomolecular structural details. On Earth we see such patterns extensively on cave walls of all different lithologies and in a variety of other environmental conditions (e.g. temperature, moisture, geochemistry, etc.), in cryptogamic soils in arid regions, and even in higher plant patterning. Thus, the search for preserved evidence of such patterns can be developed into a robust metric of prior (or even current) life processes. Such patterns lend themselves to analysis by computerized robotic missions as well as being highly distinctive to the human eye. Because of the extraordinarily good preservation conditions within caves, such patterns are likely to be better preserved in subsurface cavities than they are on a geologically active and weathered planetary surface.

References: [1] B. Strader et al (2010) *Adv. Experimental Medicine & Biology*, AEMB. Springer.
[2] P.J. Boston et al (2006) *Karst Geomorph., Hydrol., & Geochem*. Pp. 331–344. GSA.