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HEXAGONAL LATTICE PCA OF THE MILKY WAY ASTROBIOLOGICAL COMPLEXITY

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Abstract. We simulate the evolution of Galactic habitable zone astrobiological complexity within neocatastrophic paradigm using the probabilistic cellular automata (PCA) platform. In this short talk we compare the results of our previous square lattice 2D PCA simulations with the new results obtained from the same model on the hexagonal 2D PCA lattice. Bidimensional hexagonal lattice is more indicative of the omnidirectional real world phenomena. However, its implementation requires more computational steps at the basic level of a PCA kernel, resulting in more time-consuming computation. The resulting execution times are compared with the ones required in the rectangular lattice case. We discuss whether the hexagonal lattice can become a standard in our forthcoming code implementations.

1. INTRODUCTION

In our recent studies we have simulated evolution of the Galactic Habitable Zone (GHZ) astrobiological complexity in the harsh/stimulating secularly evolving Galactic environment. At present epoch the notion of GHZ is best described as a few kpc wide galactocentric annular ring. It is embedded within the Galactic thin disk, encompassing the Solar circle (e.g., Gonzalez 2005). This part of the Galactic volume is characterized by sufficient metallicity for Earth-like planet formation and survival, as well as other conditions favorable for life. The latter include moderate supernova and gamma-ray burst rates, which can significantly constrain the life harboring abilities of Earth-like hosts (Lineweaver et al. 2004; Ćirković and Vukotić 2008). Also, the close stellar passes are not as frequent in GHZ as in the inner parts of the Galaxy, thus providing dynamical stability on timescales of life evolution.

In continuation of our previous effort at quantifying astrobiological variables, we consider the astrobiological complexity as a rough parameter describing the current level of life complexity at some small part of the GHZ. Astrobiological complexity is modeled on a discrete four state scale: **0** is assigned to dead sites, **1** and **2** are for simple and complex life respectively and **3** designates the technological civilization that could, eventually, be capable of colonizing the adjacent sites. So far we have been working on Milky Way astrobiological landscape in the neocatastrophic paradigm: complexity of the GHZ is simulated within the last 10 Gyr timespan influenced by secularly evolving catastrophic events (mainly gamma-ray bursts and supernovae) that can sterilize life-bearing sites (cf. Annis 1999).

Our probabilistic cellular automata (PCA) simulations are iterated on a bidimensional square lattice (GHZ ring at the plane of the Galactic Disk). The highest spatial resolution achieved is 10 pc with a time step of 1 Myr. Previous toy model unidimensional simulations of ours have indicated that neocatastrophic paradigm can lead to astrobiological phase transition effectively resolving and illuminating classical skeptic anti-SETI arguments (Fermi paradox, Carter's argument, the Rare-Earth hypothesis, etc; e.g., Vukotić and Ćirković 2008). However, 1D models are necessarily limited in the range of displayed evolutionary behaviors, which prompted the development of 2D cellular automata. The 1D results were preliminary confirmed with our bidimensional simulations that lack quantitative rationale which can be achieved throughout parallel computing and better understanding of GHZ concept and underlying timescales. In this paper, as a further improvement to our current research, we discuss the benefits of transition to the hexagonal lattice based PCA and compare some very preliminary results with the results of square lattice model.

2. WHY GO HEXA?

When it comes to space tilling ("tessellation") probably the most common requirements are that it should be regular and isotropic. However in two spatial dimensions it is not possible to make a regular lattice of circles (the most isotropic tile there is) as there would be an unfilled space between the tiles. So how should it be done? Turns out that mother nature already has the answer. Regular hexagonal lattice, usually found in bee hives, is the closest possible match to the isotropism of a circle. It is not possible to make a regular grid of octagons, or pentagons; hexagon tile is the best there is. Another reason that can be important is that the circumference to surface ratio for a regular hexagon is the smallest amongst all other regular convex polygons with less than 6 sides. This could be beneficial for PCA based simulations as there is less boundaries to worry about, requiring less computational time.

3. IMPLEMENTATION

We have modified the code described in (Vukotić 2010 and references therein) to have a hexagonal PCA mechanics. Other parts of the code are essentially left unchanged. The lattice cells are memorized in a bidimensional matrix as was the case so far. The square grid Moore neighborhood is replaced with the simple hexagonal neighborhood of radius 1 (see Figure 1). Corresponding square lattice neighborhood (which is effectively operated by our code) is also shown in Figure 1 (two different cases for odd and even column index are presented). We have used hexagonal lattice orientation shown on Figure 1. The width of the regular hexagon oriented as in Figure 1, is $2/\sqrt{3}$ times its height. Instead of using regular hexagons we have used hexagons with height that equals their width. Consequently, the distance between the hexagonal lattice rows equals the distance between the columns in the same lattice. This was necessary so that the number of hexagonal lattice cells per unit area of simulated bidimesional GHZ stays the same as in the square lattice case. The coordinates of the hexagonal cells centers are also correspondingly shifted (Figure 1).

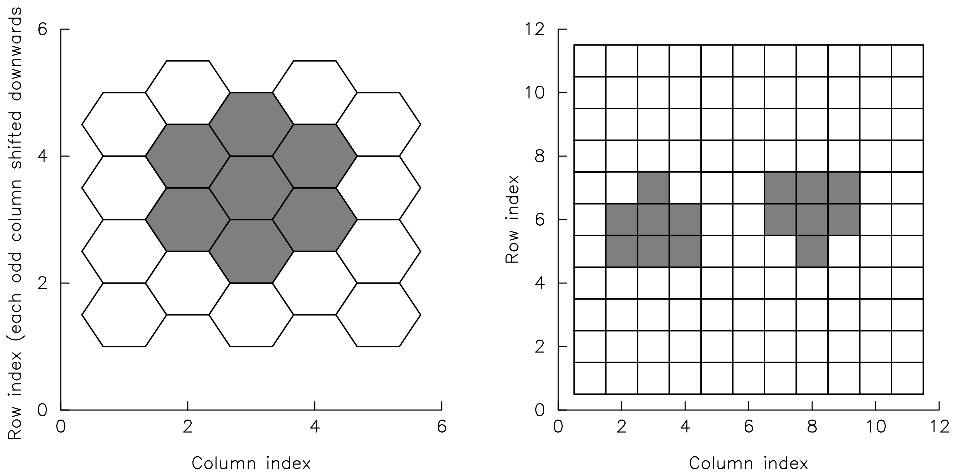

Figure 1: Left panel: Our model hexagonal lattice sample with simple radius 1 hexagonal neighborhood. Right panel: Square lattice analog of simple radius 1 hexagonal neighborhood.

4. COMPARISONS AND DISCUSSION

The PCA transition probabilities are sampled from evolutionary timescales modeled as Gaussian probability density functions. The scale lengths and corresponding transitions are given in Table 1. Spatio/temporal resolution is 100 pc/Myr. The rest of the simulation parameters are described in Vukotic 2010. Hexagonal lattice version requires similar processing time as the Moore neighborhood PCA iterations on a square lattice. We have noticed no significant benefit or handicap of this approach.

The astrobiological complexity evolution is plotted in Figure 2. We have applied the same set of catastrophic events in both cases. Any difference between the square and hexagonal lattice case is solely attributed to the lattice characteristics and consequently different neighborhoods. Inspection of Figure 2 shows a noticeable gain in state **3** cells of the square lattice case when compared to the hexagonal tessellation. The state **3** cells gain is also reflected in a consequently smaller number of state **1** cells. We think that state **3** gain is caused by more efficient colonization (Table 1) because of the larger number of possible colonizing agents (8 adjacent Moore neighborhood cells against 6 adjacent simple radius 1 hexagonal neighborhood cells). However, this matter requires further investigation and confirmation. More efficient colonization channel $\mathbf{1} \rightarrow \mathbf{3}$ transitions, than a step like $\mathbf{1} \rightarrow \mathbf{3}$ channel via $\mathbf{1} \rightarrow \mathbf{2}$ and $\mathbf{2} \rightarrow \mathbf{3}$ transitions can be attributed to more efficient colonization timescale (Table 1). Different selection of relevant timescales will result in different interrelations amongst total number of cells in different states thus changing the landscape presented in Figure 2. Total number of cells in state **0** is not affected by the lattice type because the colonization of state **0** cells is not allowed in the implemented model.

Table 1: Relevant input timescales.

Gaussian mean [yr]	Gaussian st. dev. [yr]	description (PCA transition)
1.0E09	1.0E09	life genesis ($0 \rightarrow 1$)
3.0E09	1.0E08	appearance of complex life forms ($1 \rightarrow 2$)
6.0E08	1.0E08	noogenesis from complex life forms ($2 \rightarrow 3$)
1.1E08	1.0E07	colonization from surrounding cells ($1 \rightarrow 3$)
1.1E08	1.0E07	colonization from surrounding cells ($2 \rightarrow 3$)

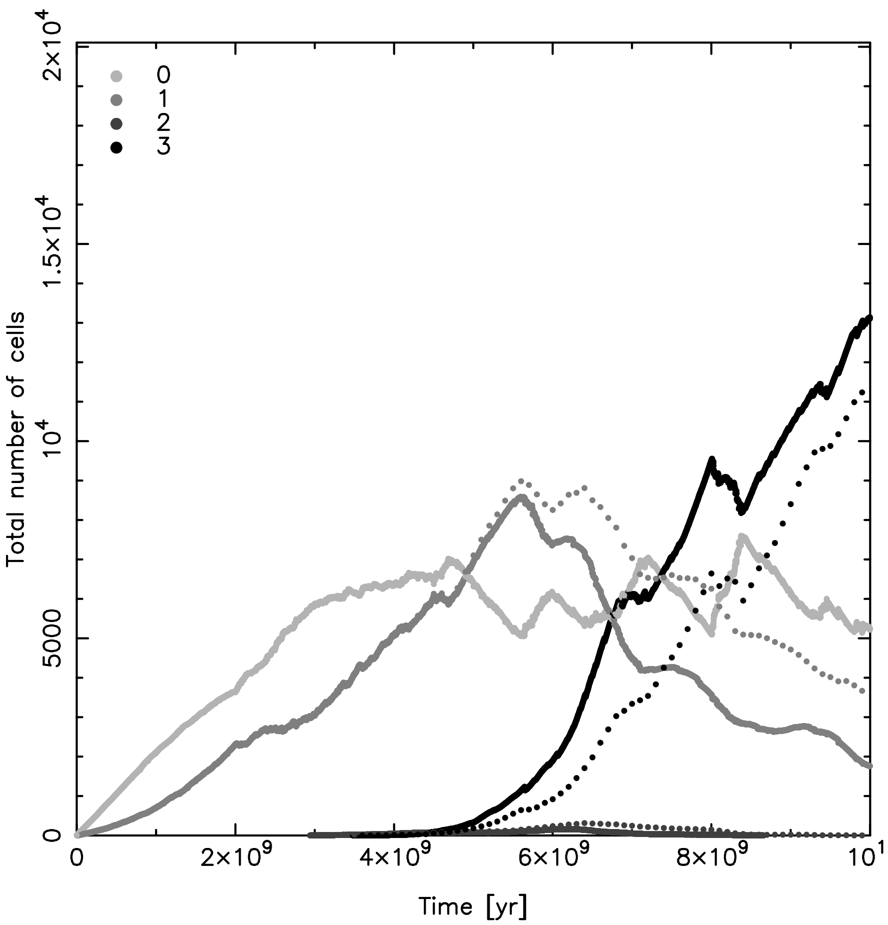

Figure 2: Total number of cells per state with grayscale-coded astrobiological complexity. Solid lines – square lattice case, dotted lines – hexagonal lattice case.

Since this is largely work-in-progress, it is difficult to gauge the relative significance of hexagonal PCA models in comparison to more conventional square lattices. This is especially true since this is the first attempt to quantify variable so essential as the astrobiological complexity through an advanced numerical methods such as cellular automata. It is our hope that the present work will inspire further such attempts in the rapidly developing and transforming field of astrobiology.

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