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The Dynamics of Brazilian Rock Art Landscape: An Agent-Based Modelling Approach to Theories

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Abstract

The first attempts at synthetizing the diversity of Brazilian rock art sites and the spread of graphic similarities envolved a certain amount of environmental determinism and traditionalism. We propose an agent-based model able to verify the possible effects of theoretical perspectives on the landscape. Our model uses a number of hunters moving randomly and a set of shelters where they can make new paintings according to simples rules. Three different mechanisms can be modified: exogenous (by nature, some shelters are fit for painting and not others), endogenous (by culture, some shelters are preferred by each hunter, and not others) and cumulative (shelters with paintings are more attractive). Compared to the archaeological context, only exogenous and cumulative constraints seem able to result in a landscape where a few shelters are concentrating most of the paintings. Endogenous constraints alone seem unable to produce the same results without another mechanism for transmission.

Keywords: agent-based modelling, archaeology, rock art, Brazil

Introduction

When studying the relations between rock art and the landscape, it is not uncommon for archaeologists to have a kind of static approach. Geographic features, such as drainage systems and elevation changes, are looked at and compared with the site location. Present-day vegetation and, if possible, paleoenvironments are studied as a whole. Despite the fact that very few sites are the result of a single occupation, we tend to forget that none of these prehistoric artists saw exactly what his or her predecessors – and followers – could actually see. Some authors even argue that each occupation was able to abstract and mentally delete all previous work. And yet, they chose the very same spot.

In this article, we propose an analysis of different theoretical approaches used in Brazilian rock art studies through agent-based modeling, in order to identify possible variables in the process of landscape formation (Cegielski and Rogers 2016). While our concerns and hypotheses are grounded in Brazilian archaeology, it could easily be translated and adapted to other contexts around the world. The next sections have been adapted and formatted according to the ODD protocol (Grimm et al. 2010).

The Model

Purpose

Brazilian archaeology has a long tradition of environmental determinism. It has roots in Julian Steward's cultural ecology theory and was imported by Betty Meggers and Clifford Evans during the 1960s, at the time of a large project sponsored by the Smithsonian Institution, called Programa Nacional de Pesquisa Arqueológica (Funari 1999). At the time of these large continental classifications, the easternmost part of South America was labeled "marginal" as semi-arid environmental conditions were deemed

Figure 1. Location of the main archaeological occurrences of the Nordeste Tradition in Brazil.

as unfit for complex cultures (Silverman and Isbell 2008, but see mostly pp. 3-28). Academic interest grew in the late 1970s, when a large series of rock art sites were identified and studied in the northeast region of Brazil. The Serra da Capivara would quickly become a locus of heated discussions and debate as dating started to lean more and more towards a late Pleistocene occupation (see Meltzer, Adovasio, & Dillehay 1994; Pessis, Martin, & Guidon 2015).

Leaving the question of antiquity aside, these new sites quickly indicated to archaeologists a larger than expected human occupation for the Holocene period. Palaeoenvironmental studies also showed that those dry and harsh conditions visible today in these regions appeared around the Middle Holocene – later than the oldest widely accepted occupations at that time these sites were found. Changing perceptions of this landscape became a matter of discussion amongst archaeologists and they adopted the concept of environmental refuge.

Following a definition by Jürgen Haffner in 1969, Brazilian geographer Aziz Ab'Saber (2003) defined refuges as those areas where rainforest reaches its maximum retraction under negative conditions (see Prance 1982). In the Northeast region, many refuges are associated with highlands, such as brejos (altitude swamps) and serras (mountain ranges). Archaeological sites in these areas, particularly visible ones like painted rock-shelters, were linked to these cycles of growth and retraction (Ab'Saber 2003).

Refuge theory was seen as a deterministic, yet semi-dynamic, framework to understand long-term occupation in the Northeast. The Serra da Capivara, as well as areas in the Seridó and the Chapada Diamantina, have since then been interpreted in the same terms for the whole Holocene period, when climate gradually shifted from wetter to drier conditions (Araújo et al. 2005).

Archaeologists formulated a second approach of cultural transmission: the concept of tradition. First coined in the 1960s to acknowledge recurrences of style and themes, archaeologists then expanded and used it as a classification scheme. Behind the repetition of similar paintings, a tradition means that artists transmitted a specific knowledge from one generation to another, during long periods of time and in significantly large areas (Prous 2005). Today, occurrences of the Nordeste tradition are broadly dated between 10,000 years BP and 6,000 years BP, in a region covering more than 500,000 km² (Martin and Vidal 2014).

Just like the refuge theory, a system based on this concept of tradition implies the existence of an initial configuration at some point in the past, from which there would be very few changes, like moving to a neighboring valley or adding a few details to the main graphic corpus. Unfortunately, there has been very little discussion on the real content of such traditions. They have been used in Brazil as a general explanation, without any further detail on their effective mechanisms.

We propose considering these two determinisms as exogenous (nature-based) and endogenous (culture-based). Both mean that the choice of new paintings in a new location is given by a set of rules that has been predefined, be it externally or internally. Does this difference have an influence over the landscape? Can it be used to help us better define the concept of tradition? What are the alternatives?

Our main purpose, then, is to study clustering. This phenomenon is occurring at multiple scales in Brazilian rock art studies:

1. A figure has to be identified individually, as to where the painting starts and stops;

2. A panel is broadly defined by blank spaces between groups of figures;

3. A site is a collection of panels on a particular outcrop or shelter;

4. An area covers a series of sites in an environmental or geological context.

The first three conditions listed above are common to most rock art studies around the world. The fourth condition of analysis, while also occurring in other parts of the world, is expected to reveal a particular combination in each new case.

In northeastern Brazil, this last type of clustering is particularly interesting when considering sites showing figurative art. Two large clusters have been studied in the last decades: the Serra da Capivara and the Chapada Diamantina. Despite their similarities in terms of style and complexity, there is a 300 km gap between the two. Between these areas there are completely different categories of paintings, mostly non-figurative. If we assume archaeological surveying has been properly undertaken, there must then have been a very precise choice or strategy as to where and how to place rock art, at a regional scale.

Entities, State Variables, and Scales

The model was written with NetLogo 6.0.1 (Wilensky 1999). It is based on two sets of agents.

- One agent is rock-shelters, used as non-moving agents with two attributes: the number of paintings, and a value symbolizing their quality. Here, quality is defined as a very general and undefined variable that would broadly include stone properties or ritual aspects. It would be whatever reason one could have to be attracted by it.

- The other agents are hunters, who could represent a single person or a whole ethnic group. They move randomly on the territory and have no attributes. Their activity is unique: painting.

- Furthermore, the world they evolve in is composed of patches, which have specific coordinates and a variable used in the process of calculating the hunter's cognitive map, as detailed below.

The whole territory has not been defined in terms of a precise scale. In general terms, it could represent a few km² or a whole region. We expect that two neighboring patches are sufficiently distant that they have no or few influences on one another.

Process Overview and Scheduling

The basic principles of the model are quite simple. Randomly reaching a rock-shelter, a hunter uses the quality variable to decide if it is possible, or convenient, to add a new figure. The attribute is a threshold against which a random number test is made. If the test fails, that is, if the random number is superior to the threshold, the hunter will just continue to move until it reaches another shelter. If it succeeds, a new painting is added to the rock-shelter, and the hunter continues to move on. The models stop when the first rock-shelter reaches a hundred paintings.

On every tick, each hunter has the opportunity to make one move and, eventually, one painting, on a turn-based logic. Time has not been defined in terms of scale. Just like the size of the patches, it could represent a day or a year. We expect both these scales to be set in accordance (i.e., a day for a small area, a year for a larger one).

Design Concepts

The main question at this point is the definition of the main variable called "quality." To avoid unending discussions as to how exactly people were deciding to draw paintings or not, the content was deliberately kept undefined – it just could be anything. It represents the fact that, at some point, for some reason, a decision was made on a certain basis. How exactly this basis was determined, externally or internally, is what draws our attention.

Coding such a variable when it is defined externally is relatively straightforward. In this perspective, a unique environmental configuration is given. It is common to all the hunters. Rock-shelters are sandstone or limestone, high or low, exposed to rain or not, etc. No human action could ever change such a configuration. At the start of every run, the program just gives the attribute a random number between 0 and 10. Low values mean poor conditions, while high values indicate particularly good conditions.

Indeed, such environmental variables seem to have been, at some extent, a real motivation for site location in the northeast region of Brazil. In the region of the Chapada Diamantina, in the state of Bahia, there is a clear difference of style, pigmentation and motives between the neighboring calcareous and sandstone regions. In Morro do Chapéu, many large sandstone outcrops bear figurative and collective scenes while, in the limestone basin of Irecê, which is also drier, there is a particularly high concentration of geometric designs. Natural properties thus played an important part in the choice of places (Etchevarne 2007).

Defining the same variable internally is more complicated. From this point of view, each hunter needs an individual definition of what is an adequate place to make a painting. Again, there wouldn't be any precise content, and such a definition could range from the shape of a boulder matching a mythological figure to the location along trade routes.

The cognitive map was generated with a matrix of the size of the world, here composed of 33 by 33 cells. Each patch of the matrix is filled with a random number, corresponding to the value given by a particular individual for this spot. As every hunter gets his own matrix at startup, the shelters end up with a number of quality variables equal to the number of hunters. Their value ranges from 0 to 10, depending on the random number of the patch in which they were created. Again, a low value means that, for an individual hunter, a shelter is not a proper place to make a painting. Importantly, in this case, two hunters can have very different ideas of what is proper and what is not.

In order to choose between one perspective and the other, each variable was also associated with a slider going from 0.0 to 1.0, called mod.amb and mod.cult. In order to analyze how external definitions affect the landscape, we have to zero the cognitive map slider; on the other hand, we have to zero the environmental definition to consider an internally defined notion of place.

Initialization

At time 0, a user-defined number of shelters and hunters are randomly spawned, all with their own variables already set. Those values will be used according to the relative importance the user wants to give them with the modifier sliders. Each run of the model will then generate a different scenario, even when the configuration remains the same.

Analysis

We ran the model a number of times with each configuration, and the results were analyzed with a few metrics. First, we gathered statistical data on each final distribution: the sum of all paintings, the mean number, variance and standard deviation. We displayed a sorted distribution for each shelter, from the most to the least painted, as well as the ratio between paintings and ticks. Second, we added more precise information about the dynamics of the landscape

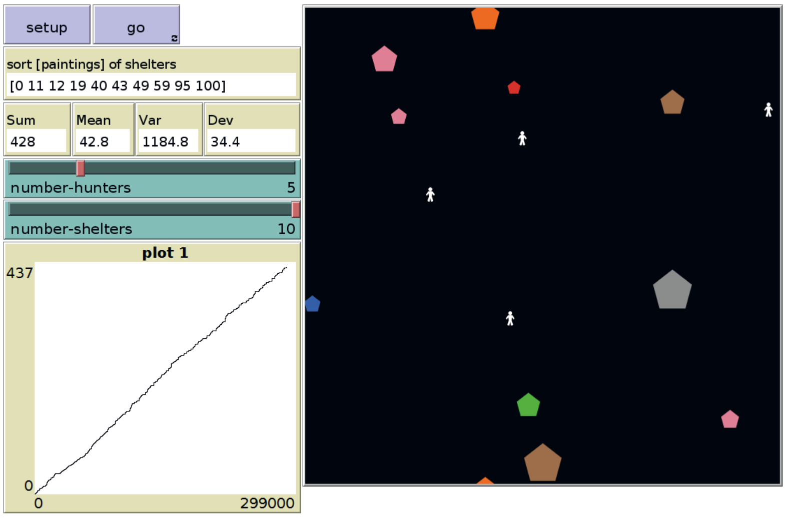

Figure 2. A typical context generated under the exogenous approach, with three large shelters and a few smaller. Two sites have no figure at all.

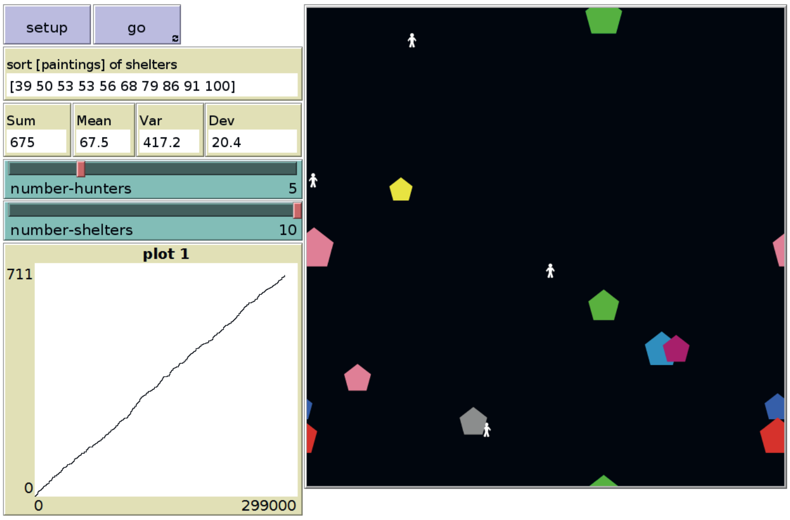

Figure 3. A typical context generated with endogenous configuration, resulting in a fully populated landscape.

construction, with a plot giving the evolution of time against the sum of all paintings.

We first looked at the environmental scenario, where a single threshold value is given externally for each shelter. As expected, those sites with the highest threshold received significantly more paintings than those with a low value. For a series of 10 runs, based on 10 shelters and 5 hunters, we found a mean sum of 552 paintings per run, with a variance of 1064.2 and a sigma, or standard deviation, of 32.6. These results confirm the high differences between the shelters: some are densely painted and others are not.

This scenario points to a high clustering, which is particularly interesting for us, as it matches a phenomenon we observe in real archaeological context: some outcrops are fully painted while the neighbouring ones may be completely empty. The dynamic plot, nonetheless, shows a regular, linear evolution, meaning the same number of paintings has been regularly added across time.

The second scenario was based on a cultural approach. Here, every hunter gives its own individual value for each shelter, resulting in a complex array of thresholds. Because of their variability, all of these different cognitive maps have the effect of scattering the results, giving them a near-random appearance. In effect, for the same series of 10 runs with 10 shelters and 5 hunters, we had a mean sum of 812 paintings by run, a variance of 69.3 and a sigma of 8.3. Most shelters ended with a high number of paintings, blurring the variability among them.

In these terms, a cultural scenario shows very poor results for the archaeologist. Even considering the most densely painted areas, like the Serra da Capivara National Park, where more than a thousand sites have been identified so far, their general spatial distribution is more selective than these results show.

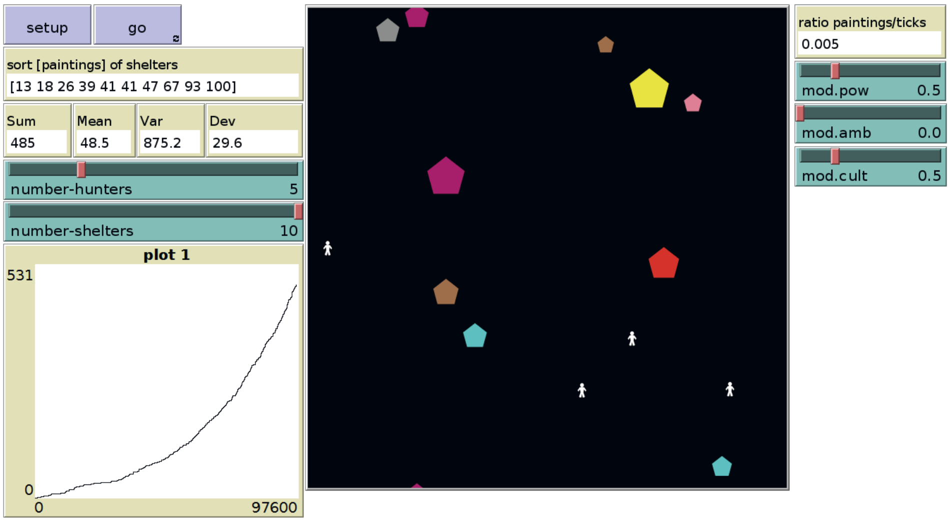

Figure 4. An example of clustering generated when the cumulative effect is relatively high (0.5). Here, half the shelters show a limited number of figures.

If we consider the kind of final landscape our model creates, we should expect it to match one an archaeologist could study in the field. In this case, an environmental perspective seems best fitting because it is able to produce clustering. Shelters receiving a higher value are always preferred to those with low threshold values. An endogenous definition of places, on the other hand, is tied to each hunter and results in a scattered, near-random distribution of rock art. These results are not very satisfactory, because they do not match the archaeological data collected to date.

Resuming the whole process of creating paintings in rock-shelters to a limited set of variables is, of course, a shortcoming. The utility of such a model lies in its ability to test our hypotheses and, eventually, to indicate flaws. In this case, we have reduced a complex reality to two agents: rocks and hunters. The result of their interaction – paintings – is our primary interest and yet, it has been treated as a by-product, completely irrelevant to the whole process. The number of paintings appears only in our statistics, and it has no influence over the movement or the threshold.

Sub-Model: A New Mechanism For Transmission

In the introduction, we presented this dual approach between nature and culture as a theoretical choice, possibly unconsciously made, by many researchers. In the model, the idea of a cultural transmission is reduced to the fact that each hunter, who might also represent an ethnic group, has been using a single static cognitive map through time. Their contact with empty sites or previously painted shelters was of no importance. Such lack of a real mechanism for transmission may explain our unsatisfactory results.

If we ca not assume archaeologically that different hunters or ethnic groups were in direct contact, the only way to establish some kind of interaction would be indirectly, through the paintings. As we have seen, the site formation is a dynamic process, growing and unfolding as more and more people used the same location to paint their graphics. That is, as we understand it, a cumulative effect. It means that the number of paintings in each rock-shelter cannot remain a hidden variable, used only for statistics.

To insert this hypothesis into the model, we added a string defining that a certain value would be incremented to the threshold based on the number of existing paintings in a shelter at the moment of each new test. Thus, even a place disregarded for painting by most hunters could end up with a significant number of graphics if a single agent was able to make a head-start. Hunters disliking a specific spot could also be motivated to make new figures if the shelter is already well decorated.

Running this configuration requires using the mod.cult or mod.amb sliders. Indeed, a cumulative effect alone is not able to create any landscape at all, as it needs, at the very least, one first painting. As our aim is to examine its role on an endogenous definition of the threshold, our tests are made with a balance of the two sliders, mod.cult and mod.pow, each at 0.5. The average values are shown on a table, always considering 10 shelters and 5 hunters, based on 10 runs each.

Sum	Var	Sigma	mod. pow	mod. cult
767.8	261.4	16	0.1	0.9
635.6	480.2	21.8	0.2	0.8
607.4	492.8	21.2	0.3	0.7
642.2	535.9	23.1	0.4	0.6
455.2	671.8	25.8	0.5	0.5
469.6	698.6	26.3	0.6	0.4
375.4	830.7	28.6	0.7	0.3
431.2	849.9	29.1	0.8	0.2
383	1099.2	32.9	0.9	0.1

Table 1. Average cumulative effect applied to endogenous rules results in clustering as the weight of each new painting grows.

We can then assess the variation with a pure endogenous scenario. The changes are visible even with a low cumulative effect: there is a significant drop in the total number of figures, and the statistics show higher variance and standard deviation, indicating that the distribution is more concentrated. The scattering effect of having different hunters giving different values to each shelter seems to be balanced by the attraction of the painted locations. Most runs now show some clustering.

Furthermore, this cumulative effect is also able to change the shape of the landscape construction, plotted as a relation between the total number of paintings by ticks. The plot is not linear anymore, as it becomes easier to make new figures on those shelters where a number of paintings has already been drawn.

Discussion

The whole model reduces a complex situation to simple agents moved by basic rules in order to illustrate how a rock art landscape may have been generated. At first, our tests confirmed that a configuration based on nature, external to human decision, was the only one able to reproduce a clustered landscape where only a few sites are selected to receive paintings. Indeed, when we considered that each hunter or group of hunters defined his own cognitive map internally, the associated landscape showed a near-random distribution. Most shelters were heavily painted as, even when a single hunter didn't value a particular spot, another did. This led us to question the concept of a cultural transmission as "tradition" without explicitly defining any working mechanism.

In order to show how the model could be used to enhance the definition of tradition, we decided to add a variable known as "cumulative effect" that could work as a locus for indirect interaction and transmission between different hunters. In this new context, the paintings left by other agents on a rock-shelter have an effect of the next hunters' behavior. As a result, we showed that a simple cumulative effect was a possible mechanism to explain the construction of a clustered landscape. Yet, this kind of rule doesn't behave like the first exogenous approach: it does not produce clustering on every run. On the contrary, it remains dependent on initial conditions, and shows our real, archaeological rock art landscapes as a matter of probability, or trajectories.

The term tradition has first been defined on a stylistic argument. As the years passed, a new element called emblematic scenes was added to the Nordeste Tradition as precise complex canvases were repeated on distant sites. Yet, few discussions have been made over the mechanisms themselves. Transmission is generally assumed without debating what caused the transmission. It is not our objective to state that preferential attachment was effectively acting in the particular context of northeastern rock art sites. We show that the concept of tradition is not sufficient, in itself, to explain this archaeological spatial distribution.

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The complete code of this model, and others, is available on: http://www.github.com/Author