Organization and Complexity of Negro River Dynamics

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1.1. Introduction

This study primarily aims at discussing characteristics of Complexity of the Amazon Basin from the Systemic Ontology point of view. Our approach is similar to the one suggested by Bunge's Scientific Ontology, though we'll also work with concepts of authors such as Denbigh (1975) and Uyemov [1975]. We understand that complexity is a systemic parameter [Uyemov, 1975], of true ontological nature but still without a satisfactory definition and that only an ontological incursion can favor the formulation of such definition. Considering the effort of now a day science to build up a science of complexity, we think that new approaches are always welcome.

We acknowledge that the Amazon Basin is a perfect example of a complex system, hence aspects of its history or memory [Bunge, 1979] are complex too. Among the enormous quantity of variables that characterize the complexity of this system, the Rio Negro time series plays an eminent role in the behavior of the other series, i.e., we acknowledge that much of the behavior of the Amazon system, in its very diverse aspects, is due to the water level variation of the river.

However, classical techniques of time series analyses emphasize the search for periodicities, with the clear objective of making forecasting possible, one of the main goals of this kind of data system. The idea of predictability is associated to regularity in time; hence such techniques emphasize on turning periodical processes explicit such as we have observed in the series and the Fourier transform. A sign composed of a set of differences in intensity of some system property under study is an information system that develops itself over time. When complex, it usually can be decomposed into a predicable, periodical component overlapping a non periodical (stochastic and/or chaotic) one. Such constitution occurs in various fields of scientific knowledge and can be formalized by the relation

$$\mathbf{g(t) = f(t) + n(t)} \qquad \mathbf{[1]}$$

where "f" indicates predictability and "n" complexity. Thus, n(t) may be "noise"(in the sense of a sign that compromises a communication process, be it intelligible or not); it may be a stochastic process, or yet of determinist chaos… in short, the above relation expresses a way of conciliating "classical' behavior with complex or noisy ones.

The time series of Rio Negro has the above described character. It is representative of a process on which the characteristic of seasonality is imprinted, however without being a pure periodical process, as "contaminated" by a complex component. It is important to point at the fact that, though not being strictly periodical, it can not simply be characterized as disordered or noisy: it can be none ordered and, in spite of this, be organized. Thus, it is necessary to understand this form of complexity associated to periodicity and, beyond, understand the implications of such overlap.

Methodologically, we acknowledge, thus, the study of the evolution of the water level of Rio Negro to be advisable point of departure for a first evaluation of the Amazon complexity. The time series of Manaus used here consists of a data basis of the water level of Rio Negro near Manaus, collected daily between September 1902 and December 2002.

1.2. The Periodical Processes

When considering the Amazon system and applying the previously sketched ideas, we notice we can have an estimate of the f(t) component by means of the Fourier transform applied to the time series (as can be seen in figures 1-5). If the sign is denoted x(t), its expression in the form of waves or in the domain of frequencies is obtained by the Fourier transform.

The time series of the monthly average of the Rio Negro water level is presented in Figure 1. In this image we can observe that the DC level (the general average of the sample period corresponding to 2323 cm) was removed in order to eliminate a zero frequency component from the spectrum.

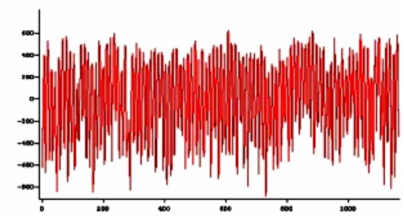

Figure. 1. The time series of the monthly average of the Negro water level.

As a result of the application of the Fourier transform we obtained a frequency spectrum of the time series, where one can see a fundamental component with a period of 12 months and harmonics with periods of over 20,8 and 29 months and of less than 6, 4 and 3 months. The spectrum presents a real part (green) and an imaginary part (red). (See Figure 2).

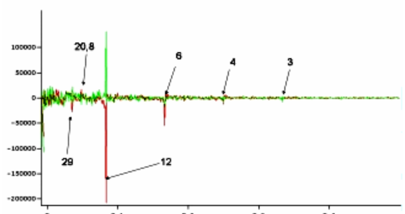

Figure. 2. Frequency spectrum of the Negro time series.

The difference between the original signal and the signal obtained by the inverse Fourier transform will correspond to a signal that strongly affects the cycle of wet and dry seasons of the river but that not have significant periodical components. This sign will be called Complex Signal. (See Figure 3).

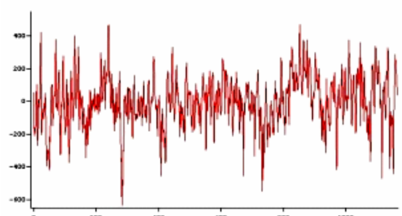

Figure. 3. Complex Signal.

What is left, however, is to decide about the nature of the complex component, the disturbance or fluctuation, n(t). It is quite natural, in the present context, to start the discussion considering the possibility of the component to be of chaotic nature.

1.3. The Delayed Phase State

A time series, be it coded or not, is a system. From Uyemov [1975] we learn that a system is an aggregate or set of things or elements related in such a way that they manage to share properties which become common to these elements:

$$\mathbf{(m)S = df\ [R(m)]P} \qquad \mathbf{[2]}$$

in the expression, the aggregate (m) is equivalent to an alphabet $A = \{xi\}$. The system is one-dimensional in its representation, in the form of a chain of signs. Such signs are connected by a set R of relations, which is acknowledge a priori for the series (classic analysis of time series acknowledge that their terms are dependent amongst themselves). From the point of view of a stochastic process, the R set is equivalent to a distribution of conditional probabilities like $p(xi\ \ / xaxbxc ...)$ [3] where, according to the Information Theory, the sequence xaxbxc... indicates the zone of intersymbolic influence, that is, the effect that previous signs take over the "present" sign xi [Goldman, 1968]. Such an effect indirectly expresses the "force" of the involved grammar, which in Information Theory is expressed by p, for the individual signs as well as for the arrangements they have formed.

It is with this system of signs obtained from our observations (the time series) that the delayed phase space has been built; this construction, created by the observer and not observed directly in nature (we will not discuss here the ontological question of the possibility of real things to be exactly phase spaces turned concrete through evolution), enables this last one to try to expand its Umwelt [Uexkull, 1992] and acquire knowledge which goes beyond its subjective perceptual and psychological environment.

The construction of a space of $k+1$ dimensions, for $k>3$ is something of transperceptual nature. A solution is the construction of spaces or maps xt versus xt+k , that are equivalent to cuts in this multi-dimensions space, or projections [Bracewell, 1965; Packard et al., 1980]. Thus, we can indirectly follow the evolution of the sign in its history. A history implies a memory function [Bunge, 1977]; it is clear that the concept of memory is similar, if not identical, to the concept of intersymbolic influence zone, as an index of grammaticality.

When the history develops, the phase-plan is occupied, more or less, in diverse regions. Certain points never occur (they would be out of low space); other seldom occur (weak grammar rule); other occur more frequently (a full grammar, with upper limit when there is a strong tendency in the sign, such as stationary amplitudes, or periodicity, or quasi-periodicity, or yet strong correlation, etc.) Actually, in stochastic ergodic processes such as natural languages, a distribution of probabilities will lead to the occurrence of more or less provable signs, so that this would lead to the rise of regions of space of varied density.

This kind of space is a kind of sign, a rhematic legisign [CP 2, 264] that presents strong aspects of iconicity: beyond its own common indexical and iconic characteristics such as found in all the conventional schemes and graphics, it presents semiotic characteristics akin to concepts in Mathematical Linguistics, which is methodologically coherent with semiotic hypotheses in the context of peircean Logics and Ontology.

What we present here is the construction of delayed phase spaces related to a time series (Figure 4). The most important aspect, in this phase, is to make the complex character of the time series evident, that is, of the historical process that governs the fluctuation of the river water level. The appliance of Fourier transform pointed clearly at the characteristics of periodicity, especially in its seasonal aspect associated to a 12 month cycle. What is commonly expected in a process of this kind, ruled by periodicity, is the so called "cycle limit".

The image of the cycle limit appears for a delay k = 1 (Figure 4A), that is, when we compare the time series to itself with a difference of one measurement. Whatever significant correlation will reveal itself, in this kind of space, through an aggregation of phase points along the geometric position where xt = xt+1; i.e., the expected image is one of a "long" closed curve along this semi straight line. Figure 4 shows approximately this: the image of historical orbits in a closed configuration, showing an intern region free of points but with subsystems of points that suggest distinct zones. The system is less defined and dispersed in low amplitudes.

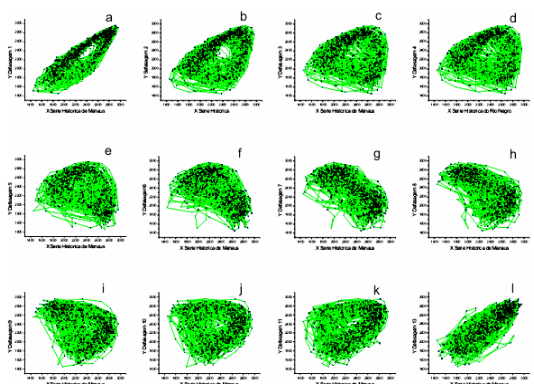

Figure. 4. Negro delayed phase space (green color represents trajectories and blue color represents dots)

When we build a sequence of Figures 4a to 4l, increasing the delay, we observe a progressive loss of the intersymbolic influence zone, with the consequent moving away from the condition of great correlation. The cycle starts to expand and to turn round; in the beginning still presenting the characteristic "opening", but gradually losing it until it seems to spin around in space. We bear in mind that this sequence of progressive differences is equivalent to a collection of maps formed by two dimensional cuts in a multi dimensional entity, as well as to a successive geometricalization of context the sign seen as a text.

If the process under focus were strongly periodical, as suggested by a precise analysis, but tendentious, from Fourier (tendentious in the sense of only seeking order and periodicity, ignoring the complexity), the delays 11 e 12 (Figures 4k and 4l) should bring the image of the cycle limit back, i.e., recovery of memory. However, despite the return of the condition of an accumulation of phase-points near the semi straight line of correlation, the periodical configuration, characterized by internal emptiness, is lost. The historical orbit entangles well, with loss of the orbital subsystems suggested in Figure 4, becoming more homogeneous. According to the Theory of Systems we draw upon, following the ideas of Denbigh [1975], subsystems are integrality indexes, the degree of organization of a system. That is, we observed a gradual disorganization of the sign in its intersymbolic influence zone.

For the delays 3, 4, 6 (Figures 4c, 4d, 4f), which could show the periods associated to harmonics found by the application of the Fourier transform, we observe the strongest aspect to be the "spin" of the orbit. Moreover this characteristic expands until the delay 8, thus not being anything much intense associated to specific harmonics.

Details noticed in the frequency domain, by means of Fourier, are not easily discernible with the technique of delayed phase spaces. The advantage of the latter is to show the complex non periodical aspects of the sign under study.

The sign of the historical series of the Rio Negro, analyzed by means of the Fourier transform enabled the analysis of the spectral components of high and low frequency separately and removed from the original sign of the historical series as to result in a sign free of periodical components. This sign can now be treated with the same techniques used for the complete sign (Figure 5).

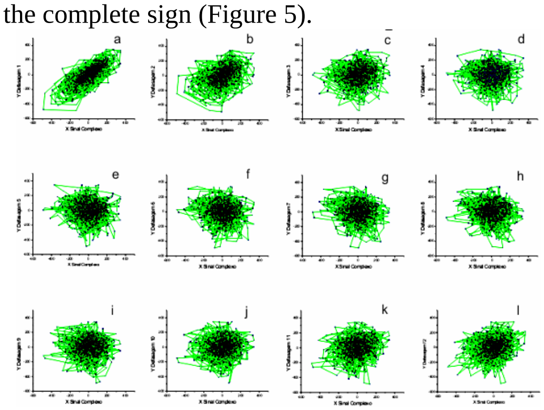

Figura. 5. Complex signal delayed phase space

The Complex Signal reveal different Images (Figures 5A to 5L). They have a closed configuration with an intern region rich in points and homogeneous pointing to randomness but they show clusters of more densities. It suggests the presence of subsystems and levels of organization. Other point so interesting is the dispersed area near of borders. This area is neither periodic nor randomic. It may represent a chaotic component of the system.

The reconstruction of the system's phase spaces starting from one single time series obtained from its own measurements, in one single property, is so important in the scope of peircean semiotics, but here we are focused only on the question of the diagnosis of a possible process of chaos.References

1.4. The Possibility of Chaos

The question of identification of a process, with respect to its chaotic or other kind of nature, is methodologically important, especially now that the theme of chaos is so successful and seduces so many in the areas of science, philosophy and arts. The problem that needs most care is exactly the elaboration of a correct diagnosis. That is, given a process that is avowedly chaotic, it can be characterized in phase spaces by the calculation of de correlation and entropy dimensions; but in the experimental analysis of unknown time series in their processuality, this method has been reverted so that a fractal dimension and entropy are taken as proof of the presence of chaos. However, there are, indeed, simple stochastic processes that lead to a correlation dimension and an entropy inducing misinterpretations [Vio and col., 1992]. Thus, among our results, which include the most typical ones of conventional statistics, such as average, deviation, standard, we will emphasize just the more specific one for our diagnosis: Lyapunov exponent.

The value of 2.26297 for the correlation function of the complete series shows us a strong grammaticality, related to seasonality of the river (Figure 6a). The filtered data show us a correlation function of 0.5865718, which means that grammaticality is much weaker and points at a chaotic process (Figure 6b).

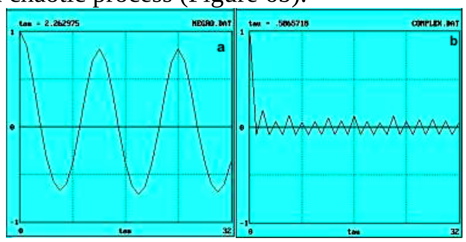

Figure. 6. Correlation function of Negro River (A) and Complex signal (b).

The highest Lyapunov exponent measured in Negro data was ~ 0,351(±0.046) positive, thus consisting in a symptom of chaos. In the complex sign, the value found for the Lyapunov exponent was ~ 0.205 (±0.037) positive, also pointing at the presence of chaos. (See Figure 7a and 7b respectively).

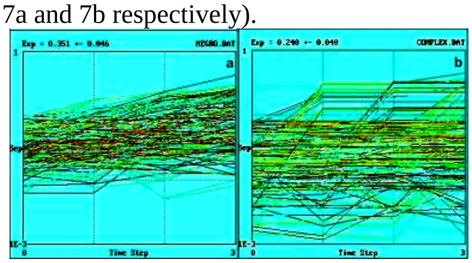

Figure. 7. Lyapunov exponent of Negro River (a) and Complex signal (b).

Though the Lyapunov exponent value found for the Rio Negro signal is higher than the one found in the complex signal, we can observe that the river signal presents a set of more compact responses; the complex signal shows us a higher variability of results. Maybe this outcome relates to the expansion and retraction movements of the orbits. A very characteristic symptom of chaos.

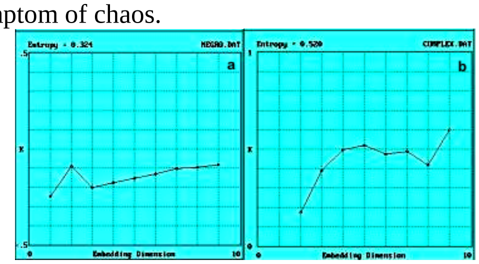

Figure. 7. Kolmogorov Entropy of Negro River (a) and Complex signal (b).

We obtained an entropy value of 0.324 for the Negro signal (Figure 7a). This value is indicative for the presence of a chaotic component. Analysis of the complex signal presented an increase of entropy, as expected. The obtained value was 0.520. (Figure 7b).

1.5. Final Remarks

The signals analyzed in this paper show us a strong possibility of chaos in the Negro river conduct. But it is important to point out that the chaos diagnosis, though always appealing from the theoretical point of view, should be evaluated with great care. One should be careful at diagnosing such kind of process, for we could easily infer chaoticity in complex signs that do not necessarily have such characteristic. Other measurements should be accomplished in order to assure a system's chaotic behavior, such as: capacity dimension and correlation dimension, Hurst exponent, relative LZ complexity and BDS statistics.

It is necessary to emphasize that such proposal is still in its proto-theoretical stage, consisting nowadays of one group of partially coherent theories of different levels. The theory has not yet presented subsystems with the necessary connectivity and cohesion to develop full and fertile coherence. This attempt to formulate a theory is a great theoretical as well as methodological attitude.

We believe that an agreement between the Systems General Theory (according to Bunge) and Peircean Semiotics, using trandisciplinary methods, will give to the Amazon basin research projects, a unique and innovative approach. In conclusion, we expect that this method would work for almost any complex system, and it is not restricted to models of ecology.

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