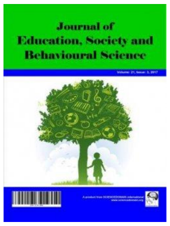

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Construction of Dynamic Academic Systems: A Preliminary Modeling

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Authors' contributions

This work was carried out in collaboration between all authors. Author NS designed the study and the algorithms, performed the analysis with authors MA and EMC. All the authors wrote the first draft of the manuscript, with a final compilation from authors MA and EMC. A final revision was made by author NS. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this theoretical study is to present and discuss a chaotic simulation model addressed to understand how an academic environment can evolve from chaos to stabilized states, providing a consistent basis to support new methodological initiatives that promote changes in the current paradigm of education.
Study Design: The study was designed from the classical literature on chaotic systems.
Place and Duration of Study: Civil Engineering Coordination, ICESP/Promove, Brasília, Brazil, between May 2015 and January 2017.
Methodology: We consider, by hypothesis, a system formed hierarchically by the class of professors and researchers of a higher education institution. This hierarchy does not reflect an organization of power; rather, it is referred to acting positions, such as research group leaders, course completion counselors, scientific initiation counselors, etc. The individuals were classified by profiles of ordered abilities represented by binary strings defining a topology. Such topology fixed the type of the strings and their transcriptions to decimal system. Three differential equations were

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numerically integrated in convolution to simulate the evolution of the system, one of them referred to those strings converted to decimal signatures. We used Maple and R language to perform the simulations.

Results: Simulations showed attractors for different time intervals of iterations. For wide ranges of individual propensities to develop the six abilities described in the work it was observed that the dissimilarities of individual profiles induced attractors with narrow boundaries. Growing the number of individuals, this tendency was maintained.

Conclusion: The study showed simulations performed on representations of academic systems consisting of researchers and professors interacting within a change-resistant environment, pointing out that these systems may evolve from chaotic configurations to stability, inducing well defined attractors.

Keywords: Chaos; attractor; interaction; self-organization; simulation; academic environment; randomness; genetic grammars.

1. INTRODUCTION

Since the 1980s, studies about the so-called chaotic systems were intensified. From this period, seminal works on the subject appeared, which became true classics in scientific literatures, both basic and advanced, such as those of Prigogine [1], Gleick [2] and Kauffman [3]. Lorenz's celebrated dynamical system [4], describing the motion of a fluid in a horizontal layer which is being heated from below, was undoubtedly one of the great icons of the motivation that has driven so many studies on the subject (Fig. 1). More recently, researchers from several fields have taken up the chaos science in contexts ranging from education, passing through management of human resources, economics and econophysics, biology, and, finally, coming to physics [5,6,7,8,9]. Within this series of new works, Juraj Šarlošia and colleagues, in a revisionist paper, sought to clarify, even briefly, the so-called deterministic chaos from the study of dynamic systems with precisely defined initial conditions [10]. Also, Qamar Din investigated bifurcation analysis and chaos control in a two-dimensional discrete-time prey-predator model [11]. Such great interest is justified by the simple fact that it is the very nature of things to oscillate between periods of great turbulence and relative stability. It is, therefore, necessary to know the laws of chaos in order to deal teleologically and efficiently with our production systems at lower rates of entropy generation. Particularly in present paper, we are dealing with an academic system of teaching and researching to make it qualitatively more effective in its results from disruptive and free interactive practices among researchers and professors. In contrast to the old classical techniques based on authoritarianism and overmuch restrictive rules with respect to evaluation practices, design of courses and research planning, this system is self-regulating and dispenses leaderships; its dynamics has direct repercussions on the performance of teachers and researchers, and tends to raise the internal level of cooperation among all academic areas, including top management sectors. This transformed and open system, where each actor interacts freely with others obtaining motivation from the interchanges practiced in events that feed cooperation, diffusion of ideas and elaboration of concepts and methods, we call <<dynamic academic system>>, or briefly <<DAS>>.

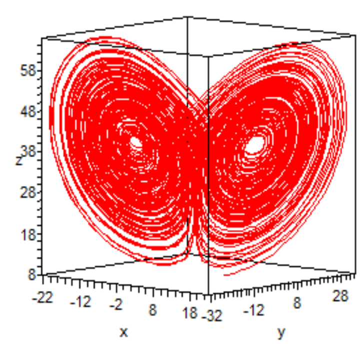

Fig. 1. Lorenz's famous cycle plotted in Maple worksheet

As far as we know from the research implemented, there are no references to the application of chaos theory in a system like the one being defined here. Thereby, our research is based on two fundamental pillars: systemic organization and chaotic deployment. Seeking a new way of seeing the world, some authors began to propose non-reductionist but integrative theories: the whole is more than the sum of the parts. Far from being a mystical proposal, this view is based on the fact that the properties that an organizational level presents are not only the sum of the properties of its constituent parts, but are due to the processes of interaction that occur between these constituent parts. To this phenomenon we call <<emergency>> [12]. Thus, systemic organization is an arrangement of actors, tools, processes, concepts and practices such that there is place to occur <<emergency>>. As a new level emerges, something even more interesting is discovered: the system does not need something external to stabilize itself. This occurs from their characteristics and the possibilities of random interactions: we have then self-organization. Thus, chaotic deployment is a broadcast of interlocking random events that trigger internal mechanisms of adaptation and regulation. Seen from this perspective, the system obeys an internal order, which allows the creation of new structures and new forms of behavior. This phenomenon is reported by several authors, such as Lewin [12] and Gell-Mann [13]. There is no need for an external organizational mechanism. The system, as said, self-organizes itself.

Now, classical education has for a long time been based on an authoritarian perspective, arising from centuries of tradition. Professor-centered model of teaching, with the preceptor as the holder of knowledge and therefore responsible for transmitting it to students, remained a prevailing view of education, despite the ever-present efforts of educators to change this picture. As an example, as related by Mamede and Penaforte, we can mention John Dewey, who, as early as 1903, stated:

> "The belief that a theory can be learned from a verbal formula was born from the conception that we first perceive things and ideas, as if they were separate items of knowledge to be bound by the function of judgment. In this way, education becomes synonymous of transmission of external facts to the mind, in the perspective that in a second stage, as a result of a natural property of the knowledge process, the discovery of its associative connections will necessarily follow" [14].

Faced with the facts, we believe that it is possible to construct a new model of teaching/ learning from unorthodox conceptions centered on chaos and self-organization. Present approach aims to show how an academic environment can self-organize from the chaos and evolve through the application of principles such as those of the active methodologies to the collaborative interactions promoted among professors and researchers, constituting what we call a DAS. Evidently, the simulations start from premises based on the randomness of the relevant properties of the system in focus, such as resistance of institutions to changes and bureaucratic obstacles. In fact, that randomness is in the essence of the more innovative and disruptive human interaction models in which the redesign of challenges and problems come from fortuitous interactions among actors that manifest their own rhythms of work and also learn from others in groups and projects. It is expected that present work sheds new light on the theoretical foundations of the main contemporary initiatives towards the adequacy of the teaching-learning process to the great changes of our society.

2. THE METHODOLOGY

This study is based on the configuration of a DAS toy model by means of computational simulations carried out on a virtually built random academic environment. The next step shall be to apply the model to professional profiles raised at ICESP Colleges, Brasília, Brazil. If the results of the simulations with the data raised are promising in relation to the new practices adopted in the institution, there shall be a strong indication that the theory can be generalized to any academic environment.

In order to discuss the way in which a dynamic communicational process with progress[1] can be implemented within the academic community, that is, a process that modifies positively and gradually the anachronistic teaching/learning culture that is currently ruling in most - if not all - Brazilian institutions of higher education, it is necessary to establish the formal bases that make up the modeling of the proposal in focus. Let us begin by remembering that, although evolution necessarily implies self-organization, this latter alone is not enough to constitute evolution. We shall understand this later.

At the outset, we consider, by hypothesis, a system formed hierarchically by the class of professors and researchers of a higher education institution. This hierarchy does not reflect an

[1] The concept of evolution with progress was well discussed by Lewis in the 1960s [15]. It is the notion of continuous evolution, that is, there is no limiting state of maximum specialization that renders the system incapable of adapting and adjusting to new conditions.

organization of power; rather, it is referred to acting positions, such as research group leaders, course completion counselors, scientific initiation counselors, etc. Obviously, it is assumed that, because it is a system, the class as a whole realizes things that cannot be done by the isolated constituents of the system. This complex (but not complicated) system is in fact a network of individual actors whose mutual interactions tend to produce self-managed, highly organized and cooperative behavior. Moreover, as well as its components, the system can only be observed through a succession of states characterized by the definition of certain variables that allow us to know the symmetries of the system. Thus, the state function that would describe a *x* (professor) member of class *X* (system) would be written as

$$\left\{\Gamma\left(X\right),\Gamma\left(X,x\right)\right\},$$

being $G(X)$ the global state function, and $\Gamma\left(X,x\right)$ the member state function. Once that objects $\Gamma\left(X,x\right)$ are in $G(X)$, they do not commute, which means they inhabit different functional spaces. Their signatures, or sets of coordinates associated with both $G(X)$ and $\Gamma\left(X,x\right)$, form a hierarchical network. Each level of the hierarchy is described by the structure

$$\mathrm{M} = \left\langle \ell, \beta^{\ell}, \tau^{\beta^{\ell}} \right\rangle,$$

in which

$\ell \rightarrow$ scale signature,

$\beta^{\ell} \rightarrow$ symmetry group at scale ℓ,

$\tau^{\beta^{\ell}} \rightarrow$ a topology on β^{ℓ} (basicaly, the coordinates at the ℓ-th level).

If we use a Hilbert space H to describe these hierarchical states,

$$\Gamma_1, \Gamma_2 \in \mathrm{H}; \alpha, \beta \in \mathcal{R} \Rightarrow \alpha\ \Gamma_1 + \beta\ \Gamma_2 \in \mathrm{H},$$

we will have for the general state,

$$\alpha\Gamma\left(X\right) = \left\{\alpha\gamma_{X}^{\ell_1}\left(\tau^{\beta^{\ell_1}}\right),\right.$$
$$\left.\left\{\alpha\gamma_{Xx_1}^{\ell_2}\left(\tau_1^{\beta^{\ell_2}}\right),\ldots,\alpha\gamma_{Xx_n}^{\ell_2}\left(\tau_n^{\beta^{\ell_2}}\right)\right\},\ldots\right\}.$$

The formalism presented above is derived from a work by Altaisky in quantum mechanics [16], taken up and expanded by Serpa in quantum computing [17], and now adapted to the present context. In order to characterize the fundamental state of the system now in conjecture and its elements, strings (or words) of binary sub-variables (six in all) have been established, whose <<bits>> (addresses within the strings) receive 0, if recessive variables, or 1, if dominant variables, according to the so-called <<six abilities>>, namely:

a. Interactivity - ability to interact with one another (person or system);
b. Iterativity - ability to replicate processes and actions;
c. Interoperability - ability to operationalize, from interactions, procedures and activities;
d. Constructability - ability to make constructs;
e. Intellectivity - ability to make ideas and concepts intelligible;
f. Transdisciplinarity - ability to overcome disciplinary boundaries, combining knowledge from diverse areas.

The letters used as identifiers for the items shall be discussed later. Each member x (professor) is titled with an ordered string, a line vector whose order of << bits >> is the order presented above, and the state of each member hierarchically included in the system cannot be evaluated independently of the levels above its own level, nor independently of the state of the same level members. It is then said that an individual evolution occurs if a new property emerges from the ground state (formed by the <<six abilities>>). This new <<ability>> adds a <<bit>> to the original string, 0 or 1 (the Kauffman <<monomers>> [3]), depending on the interactions between class elements. If, by spontaneous selection, the new property adds value to the system, making its dynamics more effective, it is said that there has been evolution of the system with progress. Theoretically, strings can grow indefinitely, and for a given length *L* of the string there will be 2^L possible types of words. Thus, the possible binary strings of length *2* are

$$A := \left\{01\right\};\ B := \left\{11\right\};\ C := \left\{00\right\};\ D := \left\{10\right\}.$$

2.1 Topology of Semi-Random Genetic Grammars

A collective of strings allows to establishing pairs of words that can be recombined according to previously fixed rules. The name <<grammar>> is given to the set of such rules. Since these rules are similar to the rules of chromosomal recombination, we say they are <<genetic>> rules. Grammars are especially useful when one wishes to test whether a model far from the equilibrium condition is driven, at the edge of chaos, to self-organizing processes, verifying if the dynamics of the system in question manifests a attracting state, that is, a state of convergence, which emerges from a trajectory that seems to make more sense than others, or that occurs more frequently during iterations. Since the word of a new element of the system consists of an arbitrary sequence of zeros and ones, according to the proposed order of the <<abilities>>, we can choose a fixed cut-off point in the strings, since the first three bits refer to the properties that characterize less complex individual performance requirements — the capacities to exert mutual action, to repeat and to put into practice the processes designed for the system —, and the last three to the higher individual capacities — the ability to create and apply new constructs, using them as connectors between different areas — which are assumed to be less frequent. For this reason — the fact that we fix a cut-off point on a randomly constructed string — we have given the name <<semi-random grammar>>. For instance, two elements with the following labels

$$\{001|011\},\ \{111|010\}$$

can be recombined as

$$\{111|011\},\ \{001|010\}.$$

Recombinations of this type are results of random interactions. Also, random mutations may occur in certain bits provoked by stimuli and motivations emerging from the dynamics of the system itself; in other words, there are behavioral adjustments based on the feedback provided by the environment itself. Now, let us take up the identifying letters of the <<six abilities>>, keeping them in the same order in which they were listed. In this way, our complete string could be written in literal form as

$$\{a,b,c,d,e,f\}.$$

Since this word is a topology, if we take all its subsets (open sets) according to the original sequence of letters — in which the recessive items are omitted — we can establish the following *lattice*:

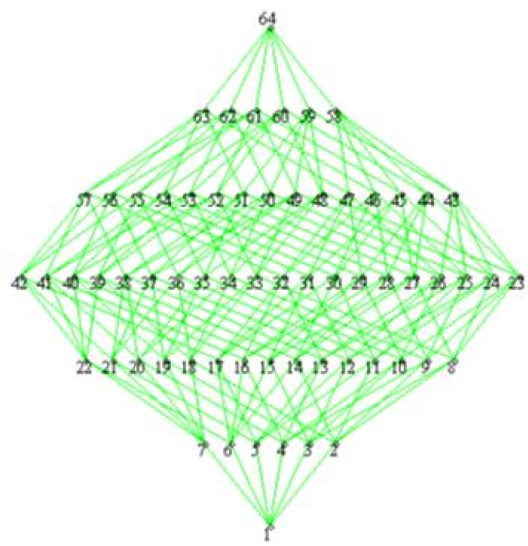

Fig. 2. Lattice of the initial topology defined in the model

or

$$\{\ \}, \{a\}, \{b\}, \{c\}, \{d\}, \{e\}, \{f\}, \{a,b\}, \{a,c\}, \{a,d\}, \{a,e\}, \{a,f\}, \{b,c\}, \{b,d\}, \{b,e\}, \{b,f\}, \{c,d\}, \{c,e\}, \{c,f\}, \{d,e\}, \{d,f\}, \{e,f\}, \{a,b,c\}, \{a,b,d\}, \{a,b,e\}, \{a,b,f\}, \{a,c,d\}, \{a,c,e\}, \{a,c,f\}, \{a,d,e\}, \{a,d,f\}, \{a,e,f\}, \{b,c,d\}, \{b,c,e\}, \{b,c,f\}, \{b,d,e\}, \{b,d,f\}, \{b,e,f\}, \{c,d,e\}, \{c,d,f\}, \{c,e,f\}, \{d,e,f\}, \{a,b,c,d\}, \{a,b,c,e\}, \{a,b,c,f\}, \{a,b,d,e\}, \{a,b,d,f\}, \{a,b,e,f\}, \{a,c,d,e\}, \{a,c,d,f\}, \{a,c,e,f\}, \{a,d,e,f\}, \{b,c,d,e\}, \{b,c,d,f\}, \{b,c,e,f\}, \{b,d,e,f\}, \{c,d,e,f\}, \{a,b,c,d,e\}, \{a,b,c,d,f\}, \{a,b,c,e,f\}, \{a,b,d,e,f\}, \{a,c,d,e,f\}, \{b,c,d,e,f\}, \{a,b,c,d,e,f\}$$

Therefore, the number of open subsets in this topology is equivalent to the 2^L possible types of words already mentioned, namely 64. Thus, an individual evolution, in the strict sense pointed out above, will lead to a topology change.

2.2 Looking for Attractors in the Model

Fixed the topology described in the previous subsection, the main idea is now to simulate a DAS chaotic model from the exchanges and feedbacks among professors of any academic environment, verifying if at the end of a large number of iterations a dominant profile of behavior is observed, that is, if the dynamics of the system leads, over the time, to states organized around a frontier of stability (an attractor), or stable limit cycle. For this purpose, it is necessary to establish three differential equations, namely:

1. Differential equation of the academic profile, considering that it can evolve continuously;
2. Differential equation of the action of the academic environment on the aforementioned academic profile, assuming that such action is continuously modified;
3. Differential equation of individual propensity to the <<six abilities>>, assuming it is also continuously changeable.

These equations were well explained in reference [7]. Without excessively deepening the technical aspects involved in algorithm programming and mathematical modeling, these three equations provide numerical solutions for performing a convolution process on the differences between the values assumed by the variables over time. Our system is conceptually similar to systems of differential equations that describe growth and stabilization of any counting involving features conflicting with one another (as individual motivation, bureaucratic barriers and profile of personal skills).

3. RESULTS AND DISCUSSION

The current algorithm is able to generate random strings and recombine them genetically according to the adopted grammar. The first simulations, performed in Maple and R language, were based on the random generation of 10 binary strings of the <<six abilities>>, the dissimilarities between academic actions (computed in terms of probabilities) and the dissimilarities between individual propensities (which are also probabilistic), for a total of 40 academic profiles randomly chosen from the 10 strings (this means there may be repeated profiles). It is observed that, considering the dissimilarities between individual propensities in a broader range of values (Fig. 3), the system tends to converge to a smaller boundary around higher ordinates (dissimilarities in the corporate environment), whereas for dissimilarities between individual propensities in a narrower range (Fig. 4) the system tends to converge to a larger boundary around lower

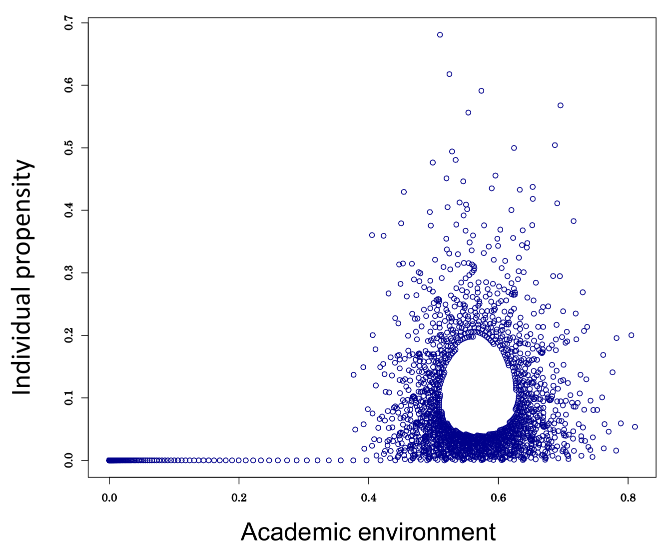

Fig. 3. Attractor for wider range of individual propensities

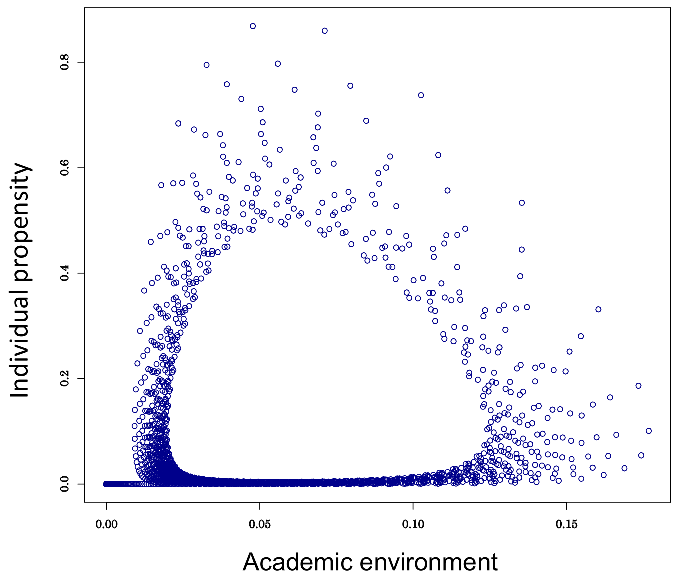

Fig. 4. Attractor for narrower range of individual propensities

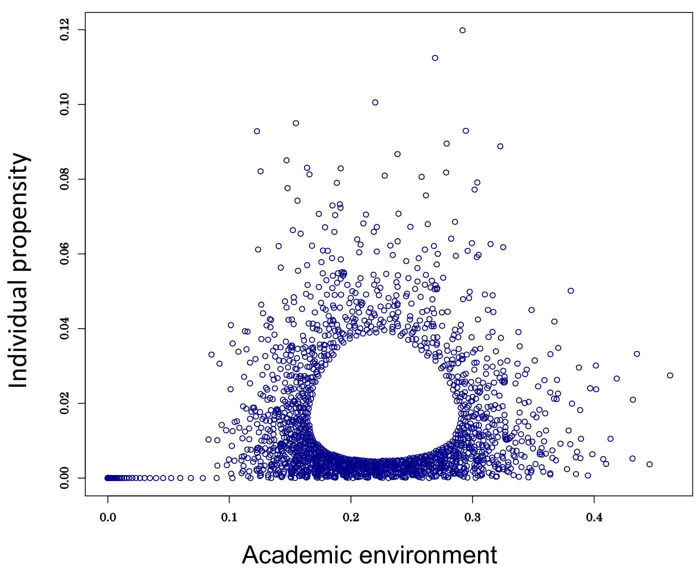

Fig. 5. Attractor for 140 individual profiles (wide range of dissimilarities)

ordinates (dragging dissimilarities in the corporate environment to smaller values). For a larger number of participants (140), maintaining a wide range of dissimilarities, the convergence occurs around a central region with respect to the axis of the ordinates (Fig. 5). Finally, a simulation for 1400 individuals, displaced towards the origin of the ordinates, showing the permanence of the attractorial symmetry for the same wide range of dissimilarities (Fig. 6). For an idea of how these evolutions appear over time, the reader may observe Fig. 7, in which one clearly sees a chaotic dispersion in the initial states tending to phases with more stability. The initial 10 strings were 001011, 110111, 101010, 010101, 111000, 111011, 000011, 011110, 110110 and 100010.

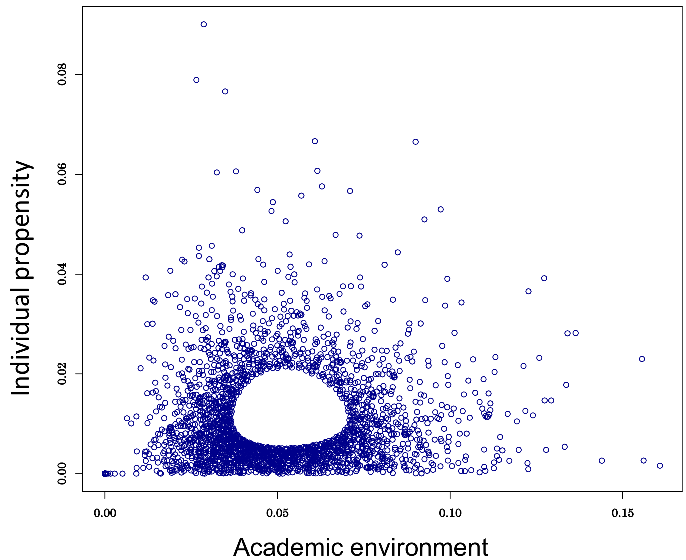

Fig. 6. Attractor for 1400 individual profiles (wide range of dissimilarities)

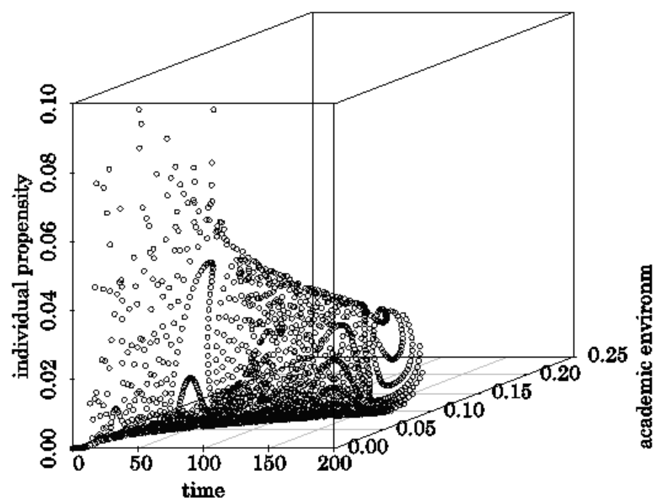

Fig. 7. Attractor for 40 individual profiles in evolution the entire time considered (wide range of dissimilarities)

4. CONCLUSION

This study showed simulations performed on representations of academic systems consisting of researchers and professors interacting within a change-resistant environment, pointing out that these systems, called DAS, may evolve from chaotic configurations to stability, inducing well defined attractors. The stability is presumed to be a new state of order achieved by continuous interchanging of knowledge and experiences among the actors in such way that it is become possible to change internal processes of teaching and evaluation, leading to higher values added to learning and more quality of teaching. Certainly, it is a theoretical model that needs to be confronted with reality by means of practical instruments of data collection. Activities that promote interaction should be organized to allow accurate observations of the evolution of the academic system. The main expected practical implications of this study are the modernization of academic processes, both administrative and teaching/learning, and the improvement of the quality of teaching, since the functioning of the model presented depends on deep institutional changes. In addition, future works may conduct complementary stochastic analyzes by assuming Markov processes on the finite number of possible individual states.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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