Chaos Theory and its Application in Political Science

Joan Pere Plaza i Font (UAB – Universitat Autònoma de Barcelona)
Régis Dandoy (UCL – University of Louvain)

To cite this paper:
Plaza i Font Joan Pere, Dandoy Régis (2006) Chaos theory and its application in political science, Paper presented at the *IPSA World Congress*, Fukuoka, Japan (9-13 July 2006).

Abstract:
The introduction of the notion of chaos – derived from the chaos theory as developed in mathematical and physics sciences – into the study of socio-political phenomena allows us to better understand the dynamic evolution of these non-linear systems. This paper intends to review the still embryonic literature regarding the application of the chaos theory in political science, particularly into the fields of public policies and international relations. The modelling and prediction attempts made using non-linear tools (such as the mathematical transformations, the fractal objects and other graphic and quantitative methods applicable to the specificities of the socio-political data) reveal the original asset of the chaos for social sciences. Using examples and cases studies, this paper attempts to develop and shows the pertinence of these original concepts (such as the bifurcations, the strange attractors, or the sensitivity to initial conditions) as well as the analysis and prediction tools associated to them in order to apprehend and understand political phenomena whose behaviour seem to be, at first sight, random or at least unpredictable.

1. The Breaking-up of the Newtonian Paradigm

Classical positivist model, which truly and largely permitted the advance of modern scientific knowledge, is somehow out-dated. This deterministic-like paradigm which run during the 18th and 19th centuries, not only based on the work of Newton but also of other distinguished scientist such as Leibniz, Euler or Lagrange as well as on the philosophical inquiries by Descartes or Comte, strongly supports what has been named as *paradigm of order* (Geyer, 2003). It is founded on four main principles, as follows: order, reductionism, predictability and determinism. By *order*, one may understand that, the given causes will lead to the same known effects. *Reductionism* implies that the behaviour of the system can be explained by the sum of the behaviours of the parts. On the other hand, this kind of system is *predictable* in the sense that, once its global behaviour is defined, events in the future can be determined by introducing the correct inputs into the model. Finally, *determinism* implies that the process flows along orderly and predictable paths that have clear beginnings and rational ends. This way of understanding behaviour of natural (and social systems) could be summarized with the following quote of Laplace (1951):

"We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes".

Nevertheless, this scientific *Weltanschauung,* describing a mechanistic world defined by differential equations, was progressively confronted to more and more complex natural phenomena which clearly escaped from these linear descriptions of the reality. All in all, it finally conducted to the assumption of the uncertainty, nonlinearity and unpredictability of natural realm (Krasner, 1990). For instance, whereas the standing paradigm assumed a linear point of view, where causes and effects are always related by proportional laws of behaviour, the new approach over the same old phenomena showed that there was no proportionality between causes and consequences, that is, small causes could produce, in a punctual moment, large consequences. But the most interesting point was, as Poincaré quickly noted, that these complex behaviours – that was not actually unknown by Newtonian paradigm, but just got around by means of linearization methods – could also be an output from a set of linear interacting equations. Although it was a real strike on the foundations of the Newtonian paradigm, some other crucial discoveries in mathematics and physics such as quantum physics or relativity theory placed in a second and discrete row all these important progress in non-linear dynamic systems (Capra, 1996).

2. Chaos and Randomness

Chaos is undoubtedly a confusing term. On the one hand, chaos belongs to the mythological heritage of many different ancient cultures, almost as a cultural universal, whereas on the other hand it refers to a very particular research program in the study of the temporal evolution of nonlinear deterministic systems.

Despite its etymological Greek origin (χάος), the notion of chaos appears in many different ancient narrations about the origins of the World. Thus, while in Egypt *nut* was the formless universe which gives rise to *râ*, the Sun God, in China dragons emerged from one homogeneous and uniform space, imposing the order *yang* to the four corners of the matter *yin* (Herman, 1994). The same narration appears also in the brahamanic legacy and of course, in the Greek cosmology where chaos is an a-historical state where time comes from. As a result of all that, there is still nowadays a tendency, revealed in our colloquial language, which associates the notion of chaos to disorder, turbulence, anarchy and confusion. These interpretations of chaos could be easily associated to random behaviour, that is a state of maximal entropy, which do not represents the distinctiveness of chaos in a technical sense.

Actually, chaos is not randomness at all. In a random system, everything is possible. Given a particular point at its trajectory, the following point cannot be predicted. Nevertheless, it does not mean that any following state can be whatever it can ever hypothetically occur. Somehow it can be one among many possible states, but not one among infinite. There is always a (wide) range of possible futures, but this range is never infinite. So, in this kind of chaotic phenomena, even if not being able to predict what is going to happen next, one may know that what will happen will be drawn from a set of alternative greater than one, but less than too many to cope with (Byrne, 1998). Said differently, in applied mathematics, chaos designates a deterministic complex behaviour, irregular and non-periodic with random appearance but maintaining a latent order. This is a very important assumption because it sets the chaos theory in a non-stochastic view of the world. This being said, however, one may not completely reject statistical practices, because even deterministic models maintain a complete collection of statistical measures and require, for instance, the application of least square procedures (Brown, 1995).

3. Phase Space and Attractors

These hidden orderly patterns in chaotic behaviour can be presented in the so-called phase space. Phase spaces are abstract mathematical spaces, that is a set of structured points, normally with a high number of coordinates (each particular variable taken into account by the model is associated to a different coordinate), so that each point in this abstract space represents a complete and detailed state which the analysed system could eventually reach. Thus, the larger the dimension (number of coordinates) of the phase space, the better will be the description of a particular state reached by the system. Furthermore, it is important to notice that any particular state of the system is represented on the axes without using a separate axis for time. This way, the evolution of any particular system could be described by a chain of consecutive points in its phase space – a chain that we will call *trajectory*. And even a trajectory can also show a random behaviour, they usually follow some trend of evolution, even if it is much more complex and a-periodical than one could firstly imagine. In a more restrictive perspective, trajectories may be also interpreted as a transitory period which system may pass trough in order to reach another stability region (Jong, 1999).

Analysing the long-term trajectory of many different nonlinear systems, just few different patterns of behaviour have been already revealed. Metaphorically, one may say that they draw just a few different shapes of trajectories. More technically speaking, one may argue that there are just few different topological forms describing those trajectories. In any case, no matter how they are presented, all these trajectories refer implicitly to the idea of attractor, because any trajectory of the system running on the long-term is somehow "attracted" by some point or some closed region within the phase space describing the system in question. And if it is not, the absence of this attractor becomes analytically relevant. And distinguishing the attractor implied in the future of the system is crucial because many general dynamic properties of the system can be deduced from the form of the attractor describing it (Capra, 1996).

General speaking, there are three different categories of attractor: (1) *punctual attractor*, defined by a single point in its corresponding phase space and describing a system whose trajectory tends to some stable equilibrium, (2) *periodical attractors*, defined by two or more "basins of attraction" which are consecutively visited by the trajectory of the system and describing the pattern of a periodical oscillatory system, and lastly (3) *strange attractors*, with no pre-defined shape and implying a chaotic behaviour.

Even if there has been some objections to the term ‘strange attractor’, such as those by the Russian mathematicians Boris Chirikov and Felix Izrailev stating that a strange attractor seems odd, strange attractors may be defined as set of points in a concrete phase space consisting of an infinite number of curves, surfaces, or higher-dimensional manifolds (Lorenz, 1993).

4. Sensitivity to Initial Conditions

A chaotic behaviour is also characterized by its extreme sensitivity to initial conditions (Gleick, 1987). This sensitivity is somehow the most intuitive characteristic of chaotic systems too (Martín *et al.*, 1995) and can be defined as follows: given a concrete point in the phase space of a chaotic system, one may find out another point, as close as possible to this initial point, and with a separation distance of $(\delta x)_0$, from which the same pattern of behaviour of the system would lead the trajectory of the system to a final point much further from the first hypothetical final point than $(\delta x)_0$. That is, in such a system, given the sensitivity to the initial conditions, the smallest perturbation of the systems in an initial condition may lead it to an exponentially divergent final state, $(\delta x)_n = [(\delta x)_0]^{\lambda n}$ (Prigogine, 1993). It basically means that the trajectories of neighbouring points may behave in a very differently way, approaching and moving away one from the other in a really unpredictable way.[1]

This is the main reason why, even being a deterministic system, most of times there exist a lack of predictability in chaotic systems. Somehow they are determined but undeterminable; hence they are sensitive to extremely low perturbations (Herman, 1994). Moreover, as measurements are mainly imprecise in the social sciences, irregular periodicity may arise from a stochastic component or from a periodic behaviour where the signal-to-noise ratio is high (McBurnett, 1997). As in sampling theory, the measurement of the difference $(\delta x)_0$ may hence induce to some errors which progressively increase and which must be labelled as *noise*. In this way, Lorenz himself stated that initial conditions can be used a suitable and acceptable definition to chaos (Lorenz, 1993).

This principle of sensitivity to initial conditions finds its parallel in comparative politics in the efforts to show how the formative characteristics of the structures and the decisions constrain subsequent processes and events (Zuckerman, 1997), since particular courses of action, once introduced, can be almost impossible to reverse and, consequently, political development is often punctuated by critical moments or junctures that shape the basic contours of social life (Pierson, 1992).

5. Bifurcation Points

It is also important to notice the explanatory importance of these critical moments, junctures or, more technically speaking, bifurcations points. These critical moments, which constantly challenge the trajectory of the system, are exactly where the sensitivity of the system to initial conditions is stronger and the chaotic nature of the system reveals itself in a more radical way, driving the system to the so-called *limits of chaos*

---

[1] Even the mathematical works in early XX century by Hadamard, Duhem and Poincaré, the most well known and popular example of a dynamical system sensitive to its initial conditions was proposed by the

(Lewin, 1992). Up to these moments, the trajectory of the system might behave in a quite predictable pattern, but once reached this so-called bifurcation point, the prior order breaks out and the system is driven by patterns of behaviour less predictable than ever before. The relationship between the order immediately before and immediately after the juncture is not simple at all (Lazlo, 1990) and, once again, it is a clear illustration of how determined and undeterminable a chaotic system might be. In other words, with nonlinear dynamic systems, the bifurcation implies a change in the system's behaviour when it is changing from one attractor to a new one (Lazlo, 1990). Therefore, bifurcations points are extremely important to understand. Because of their nature, they are not just any point. The extreme sensitivity showed by the system at these points makes them to be notorious, transcendent and unrepeatable historical moments. Actually, these bifurcations points are extremely important to understand *a posteriori* the complete trajectory of any given chaotic system.

Similarly to what occurred with attractors, there are also seldom different kinds of bifurcations, topologically classified. The first one to tackle his question was René Thom, who firstly announced the existence of seven different catastrophes, as he called this junctures in dynamical systems. Nowadays this number has enlarged until three times more (Capra, 1996). In any case, in the chaos theory (and more generally, in dynamic systems theory) any bifurcation implies a phase transition in the trajectory of a system which is evolving from one attractor to another (Lazlo, 1990). That is, in a bifurcation point a global change in behaviour arising from many changes in the many constituent elements of the system suddenly appears. Typically these interactions are short-ranged local ones, in the sense that these sudden transformations do not appear outside from the $(\delta x)_0$ distance we have already presented.

As well as this idea of breaking up the current order and also breaking up the proportionality between cause and effect, bifurcation points also exhibit a second important and distinctive property of chaotic behaviours. In each bifurcation point, the trajectory of the system becomes irreversible. It means that, once abandoned the bifurcation point, the trajectory of the chaotic system will not visit this point in the phase space anymore. Strictly talking, actually, this irreversibility in chaotic systems only refers to a so low possibility for the trajectory of the system to visit again some region (or point) of its phase space that this possibility turns rapidly into a certainty.[2] Put differently, these kinds of instabilities, which can only happen in open systems operating far from equilibrium (Prigogine & Nicolis, 1989) permit high range of possibilities, but all implying a non-way back to previous equilibriums, because in chaotic systems, particular courses of actions, once introduced, maybe almost impossible to reverse (Pierson, 2000).

This property of irreversibility, that is, never retracing previous points during its temporal evolution may be the reason of its apparent randomness (Kiel & Elliott, 1996). This understanding brings us back to the previous statements, in the sense that, even if they show a erratic appearance, chaotic systems are strongly determinate, meaning that "history matters" (Ortega y Gasset, 2001), ruling out every single possibility to univocal patterns of evolution (Herman, 1994).

---

[2] As Ruelle (1991) appropriately recognises: "Life is too short to see a layer of cold water moving up a warm water one".

6. Measuring Order

This intimate connexion between history and chaos and, more generally speaking, non-linear systems, can be also associated to the idea of "order through fluctuations" (Prigogine & Stenglers, 1984). But how to make possible an objective definition, and above all, a particular way to measure order, which seems to be crucial in order to complete this approach in progress?

Not every hypothetical state belonging to the evolution of a dynamic system has the same probability to happen. Put differently and providing a physical example to our understanding: when one imagines a child playing with a pencil and trying to let it alone, standing with no help in the middle of the desk, and even there is no physical law who avoids the pencil to stand alone, one may rapidly imagine the pencil laying on the desk after having fallen just immediately after the child left his last finger. So, even in a dynamic system many hypothetical states are possible, not all of them have the same probability to happen.

We will name complexion to every single state which can be hypothetically reached by the system for every different event (standing in the middle of the desk could be one event, while laying on the desk could be another event), so that the fewer complexions per event, the higher rank of order. This way, we are linking the idea of order to the idea of a state with a lower probability to happen.

Moving back to the idea of phase space – this singular abstract set of points representing different states reached by the analysed system – we may establish a singular classification among those scatterplots collecting those points which represent hypothetical states of the system with the same probability to happen. In spite of the many small differences among every single state, this classification however considers that all the states belonging to a same system have the same probability to happen.

Given the fact that every scatterplot corresponding to a different event collects a different number of complexions, somehow it permits interpreting every scatterplot and hence, every different event, presenting a different "volume" in the phase space of the system. According to that, it appears hence an alternative measure of the relative order reached by a system. A larger number of complexions implies a larger number of states with the same probability to happen, that is, a bigger "volume" in the phase space of the system and, and therefore a higher rang of disorder because it refers to a event with more probabilities to happen.

Due to the huge discrepancy among these "volumes" corresponding to one event or another, it is much better to compare them through the logarithm of the "volumes". We call the measure entropy. So:

$$Entropy = k \cdot \log V$$

where k is a constant variable and log V, the logarithm of the value of the "volume".

Hence, while analysing the changes in the system through observing its trajectory in the phase space, one may argue for or against an increasing or a decreasing trend, related to the rank of order reached by the system. So, despite the common opinion which compares the idea of order to some kind of perfection or desirable state, far from any value judgement, we are just proposing a likely measure of order to interpret the evolution of a chaotic system, like most of social systems are.

7. Specific Methods

The study of the chaos is in the scientific literature mainly based on a graphical methodology, on individual trajectories of variables.[3] Some specific methods have been developed to analyse chaotic behaviours and some argue that at least three different methods should be use by the researcher in order to prove the existence or non-existence of the chaos in the observed systems (Bird, 1997; Stroup, 1997). Relying on a mathematical basis, nonlinear dynamics provide relevant useful tools like the analysis of the attractors (mentioned above) or the Fourier transformation.

We will illustrate these two graphical methods and some of the characteristics of the chaos explained above thanks to a simple equation.[4] First of all, the *sensitivity to initial conditions*, that is how small effects can have large consequences. Using the following formula:

$$y_{t+1} = w\, y_t\, (1-y_t)$$

we can distinguish different patterns of behaviour according to the value of the parameter and initial condition. Graph 1 (see Appendix) concerns values of y = 0,99 and w = 2,14 and the equation is iterated 50 times. The data shows a very stable pattern that can be defined as a *constant*. Graph 2 concerns values of y = 0,97 and w = 3,13 and shows a clear and stable *periodic* pattern. These first tow graphs can be labelled as linear systems. Finally, Graph 3 presents what we can call chaos, that is a non-periodic, nonlinear and random-like system. The values for y are 0,99 and for w = 3,895. This simple example intends to prove the existence of a 'butterfly effect' even for this very simple equation consisting of only two variables. The values for y and w are respectively close to each of the values in the three above examples.

Second, the examination of a *strange attractor* (see above) is conducted by a mapping of the data into a *phase space*, that is in a t/t_{-1} phase space (t is plotted on the vertical axis while t_{-1} is plotted on the horizontal axis) (Kiel, 1993). Applying this method of phase space for our three examples, we are able to distinguish chaos from other types of dynamic systems. In the case of the system showing a constant, we observe in Graph 4 that, after the very first iterations, the system stabilises on one single point (X axis, value = 0,5327 and Y axis, value = 0,5327). This type attractor is called *punctual attractor* (see above). The observation of the phase space of the periodic system shows also a very clear pattern (Graph 5). In this case, the attractor turns around two quasi constant values, representing the periodicity of the system. This attractor is called *periodical attractor* (see above). Finally, in the case of the chaotic system, the attractor presents a very different face as shown in Graph 6. The pattern in this case looks quite complex, but not purely random. As a matter of fact, we can observe in this *strange attractor* some kinds of regularities because the system does not 'explode' in extreme variables or show an erratic behaviour. Thanks to this graphical tool, we can distinguish

[3] Even though, some authors (Sinaï, 1992 ; Dahan; Chabert & Chemla, 1992 ; Prigogine, 1993) state that the most fundamental and pertinent level of analysis of the chaos relies on the probabilities and advice to use a combination of both probabilistic and graphical analysis of the chaotic phenomena.

[4] We are of course aware that the analysis of the chaos relies on time-series data and not on time-independent artificially made data. We used this equation example as a way to simplify the – sometimes – complex behaviour of real-world time-series data.

chaos from other types of dynamic systems and it confirms the hypothesis of chaotic systems according to which we can find some kind of 'order' in the middle of the 'disorder'.

Finally and in contrast with the attractors and phase space graphical approach, only few studies used the *Fourier transform* as a useful tool to observe chaos in social sciences (exceptions are Kiel, 1993; Brown, 1994; Dandoy, 2000). Nevertheless, it appears to constitute a highly valuable method to analyse chaotic phenomena (Stewart, 1992; Stroup, 1997). Enders and Sandler (2002) observed that a Fourier approximation to non-linear estimates, instead of more traditional time series analysis (auto-regression model). The Fourier transform is also known as standard spectral analysis. Spectral analysis uses all possible integer frequencies in order to assess relative contribution of high, medium and low frequencies to the total variation.[5] As a result, if the spectrum appears to be continuous, that is if the frequencies on long, mid and short term are somehow equal, it is considered as a proof of the presence of the chaos in the dynamic system (Bergé & Dubois, 1992). Using our above examples, we can use this Fourier transform to see whether or not the spectrum appears continuous and not dominated by short- or long-term variations. In Graph 7, we observe that the spectrum indicates high values on the left of the graph, meaning that the system is almost only determined and could be predicted on the long term. According to Graph 8, the system characterised by a periodic behaviour is mainly influenced by the very short-term variations of the data (as the highest values lay on the right of the graph). As far as Graph 9 is concerned, it shows a less clear pattern, as both mid- and short-term frequencies seem to play a large role in this case. The system analysed here is therefore not fully chaotic, as it seems to be poorly influenced by the long-term variation. However, unlike the two previous examples, we can hardly observe that one of the different frequencies dominate the behaviour of the whole system. As a result, even if this last example looks closer to a chaotic system than the two previous ones, it does not seem to be made of 'pure chaos'.

8. Chaos in the Political Science

When one wants to analyse and apprehend social or political phenomena, they face a scientific object that is by definition far different form the natural sciences. Social and political scientists find out that "a high degree of unpredictability of the future is the essence of the human adventure" (Nicolis & Prigogine, 1989: 238). However, some studies and research projects have assumed, in the two last decennia [6], that chaos theory concept's and tools are inherently part of the properties of the political science. These researches concern many different topics and issues as well as refer to different aspects and characteristics of the chaos[7]. Among the latter, we can observe studies dealing with sensitivity to initial conditions, bifurcations, entropy, etc. but the majority of these studies remain rhetorical, that is using the chaos's vocabulary to describe political

[5] For more information about the mathematical definition and expression of the Fourier transform, see Dandoy (2000).

[6] Some authors consider Marx's theory as one of the first examples of the applications of the chaos theory in the social sciences before its effective development and definition by natural sciences. Marx's theories stated that social 'revolutions' (chaotic, nonlinear and dynamic) causing breakdowns in the capitalist bourgeoisie system of economy and society (bifurcations through possible dissipating structures) that may lead to a new order, a socialist system of economic and social organization with new forms of governance and administration (Farazmand, 2003).

[7] The work of Kiel and Elliot, *Chaos Theory in the Social Sciences* (1996) constitutes in this perspective one of the founding books for the application of the chaos theory in the social sciences.

behaviours and phenomena like wars, revolutions, electoral instability, or simply political problems that, on the first sight, look complex.

The recent success of the chaos can be explained by human psychology and by a perception point of view. The public – via the news media – is aware of the surrounding disorder that frustrates its desire to feel secure and creates a more intense focus on order as a prime value. In other words, the public becomes more sensitive to the disorder. "Our fear of disorder therefore makes it inevitable that we will either find or create an endless supply of it" (Chernus, 1993: 108). Crises, surprises, sudden and rapid changes, confusions and things out of control prevail in our world and characterize modern organizations and every complex system. Political leaders and managers must therefore be prepared to deal with such chaotic phenomena and manage complex organizations accordingly (Farazmand, 2003). Part of the solution can be the chaos theory that can help us understand and manage complex problems born out of highly complex and dynamic systems. Chaos systems can be distinguished from two other types of systems and each of them can directly be associated with political science. The first type encompasses systems that converge to equilibrium or a steady state, like national sentiments that often converge to a steady equilibrium. The second type concerns systems that display a stable oscillating behaviour according to a repeated pattern, like elections cycles. The chaotic system displays an irregular oscillatory process, like countries that irregularly oscillate between anarchy, civil war and democracy (Peled, 2000).

9. Public Organisations, Regimes and Policies

Some valuable scientific work has been published on chaos theory and its application to organisations and, in particular political organisations and regimes, administrative behaviour and public policy analysis and implementation. Organization theory has recently evolved to newest forms of organizational evolution characterized by instability, chaotic changes, system breakdowns with bifurcations into new orders, and negative feedbacks as well as non-equilibrium features as positive ingredients producing dynamism in the organisational system. In this perspective, the chaos theory can be fruitfully applied to improve our understanding of complex public organisations. The work activities of a service organisation seem to oscillate sometimes erratically and may, over time, appear disorderly and chaotic (Kiel, 1993). However, the management must maintain a dynamic equilibrium, or dynamic stability, that incorporates dynamism adequate for adjustment to change. Applying chaos' theory principles, each service in this organisation represents a disturbance that has the potential for altering the behaviour and structure of the work system. Thanks to a graphical perspective of managed equilibrium in a government organisation, Kiel observed that system outcomes such as order and equilibrium, or system behaviour such as stable oscillation or chaos, are empirically verifiable. Using attractors, he found out that although work activities may appear disorderly, order might exist at the foundation of the activities.

Similarly, Pelled (2000) and Farazmand (2003) observed that organizational problems, and more precisely, public administrations crises can no longer be solved or managed through traditional approaches and methods and that they require new of thinking and solutions, nonlinear complex models of action, and chaotic models to deal with non-linear situations. Introducing a time perspective, what appears to be chaotic and disorderly on the short term at the micro level may actually contribute to the long-term order and equilibrium at the macro-level. As a result, one can argue that chaos theory implies that organizations are capable of producing within themselves forces of dissipative structures most of which have self-organizing capacities that lead to new organizational entities and order. In other words, the chaos theory fosters 'dissipative structures' in hope of revitalizing the system from entropic decline. Organizations and their leadership must therefore induce periodic changes of a chaotic nature to 'motivate' the stable system for renewal and revitalization (Farazmand, 2003). More precisely, some government types can be labelled as chaotic, like democracy that is observed as inherently messy and chaotic (Pelled, 2000). Managers in organisations must foster democracy because it breeds disorder, instability and multiple inputs to decision making, qualities that are necessary in order for the organisation to change and survive (Kiel, 1994). Chaos or creative instability and the role of accidents now become the conditions upon which the pre-existence of a democratic environment where free and involved citizens can unleash their creativity. However, this perspective of the chaos theory as a tool for organisational change tends to promote deliberate chaos and destruction in societies (Pelled, 2000; Farazmand, 2003). In this sense, chaos theory can be a powerful tool of manipulation and control in the hands of few powerful elites for economic, social, political and military reasons. In addition, unpredictability of outcomes of chaotic states or systems pose further dangerous, and potentially fatal, threats to individuals, groups, cultures. – un-anticipated secondary or multiple consequences. How do we know that injecting chaotic forces into prevailing stable system will lead to eventual order, especially desired order? Could it cause massive dissipating evaporation ?

As far as the analysis of public policies is concerned, Brown (1994) observed that the environment policy positions are oscillating due to changes of partisan control of the White House and two other critical outputs, the public concern for environment and the economic costs of environmental clean-up. The model presented suggests a high level of complexity and this simplified system – only four variables – shows a clear nonlinear behaviour. The main findings of this research concern the fact that minor parametric changes in the system can lead to major alterations in the output variable – that is environmental policy changes. In addition, the author observed that, using alternate parameter values, the oscillations of the whole system are still observable, but they do not show a clear pattern. Using the Fourier analysis of the system's periodicity, it indicates a complexity very typical of chaotic systems, making any policy prediction impossible.

10. International Relations

Another 'successful' field of application of chaos theory's principles concerns the international relations studies. In its article about peace, Chernus (1993) stated that the quest for order at all costs is self-defeating. It is paradoxically that states use the military option and the war instruments – that are by definition open doors to instability and uncertainty – in order to bring order and peace in our fragmented societies. The chaos theory is particularly useful in the field of peace research. First, the more diverse possibilities are actualized in a given situation, in terms of both actors' roles and interactions between actors, the greater the likelihood of peace (Galtung, 1975). Peace will therefore occur in states with high entropy, meaning that increasing disorder, messiness, randomness and unpredictability will bring more peace than it could occur in predictable and excessive ordered countries. Second, chaos theory aims to model whole systems, looking at overall patterns rather than isolating the cause-and-effect relations of specific parts of a system (Mesjaz, 1988). Through this approach, chaos theory has discovered that many social systems are not simply either orderly or disorderly. Some are orderly at times and disorderly at other times. Others, which are in constant chaotic motion, yet display an overall stability. As a result, this notion of stable chaos and ordered randomness points the way to a new understanding of peace. The chaos theory may allow us to see the nature and the society as inherently peaceful not because they are so orderly but, rather, because they are so laden with disorder. "Nature would become the model for peace not only because of its diversity and associative qualities but especially because of its transcendence of the distinction between order and disorder" (Chernus, 1993: 113). Third, similarly to the repeated patterns of ordered randomness at different scales, the author considers peace as an uninterrupted flow of ordered randomness replicated at every level of human interaction, from nuclear family to the nations. In other words, it takes many peaceful polities to create a peaceful environment, and many peaceful environments to create a peaceful global polity, every level of policy showing a harmonious pattern of organisation.

Betts (2000) observed a useful application of chaos to strategy and international security. In his view, doubts about government's capacity to cause intended effects through strategy are reinforced by the chaos theory, given the fact that the strategy results do not follow plans. The complexity and the contingency preclude controlling causes well enough to produce desired effects and little connection between the design and the denouement of strategies is observed. The author stressed that the chaos theory emphasizes how small and untraceable events produce major changes, referring to the 'butterfly effect' characteristic. Chaos theory sees war as a nonlinear system that produces 'erratic behaviour', through disproportionate relationships between inputs and outputs or synergies, and in which the whole is not equal to the sum of the parts (Beyerchen, 1992). However, Betts conceded that chaotic nonlinearity is common in war strategies, but neither absolute nor pervasive. "If chaos theory meant that no prediction is possible, there would be no point in any analysis of the conduct of the war" (Betts, 2000: 20). Those who criticize social science approaches to strategy for false confidence in predictability cannot rest on a rejection of prediction altogether without negating all rationale for strategy. Finally, one should mention that the nonlinear perspective misrepresents the structure of the problem as the military strategy seeks *dis*equilibrium, a way to defeat the enemy rather than to find a mutually acceptable price for exchange.

More precise but still rhetorical examples of the application of the chaos theory in the field of the international relations can be found in the example of the spontaneous and mass revolutions as the Iranian revolution of 1978-79 that is considered a massive rupture of chaotic uncertainties and bifurcations into unpredictable dynamical changes in a political system (Farazmand, 2003:341), similarly to the predictions made on the post-Castro environment in Cuba (Radu, 2000). A single man –Hilter – was considered as the 'butterfly's wing' that could cause the German system to bifurcate from democracy to totalitarism (Peled, 2000:31). Similarly, the events of September 2001 in the United States, the appearance of the Macedonian Alexander that ruled the Persian Empire are assessed as good examples of how small scale chaotic events can lead to large scale chaotic consequences with far reaching implications (Farazmand, 2003:353). But political scientists do not only use metaphors for describing political and IR phenomena. For example, Saperstein (1988) studied empirically whether the development of SDI in the United States would lead to a transition from an offensive to a defensive mode of strategy from ICBM attacks. His complex model appears to be sensitive to noise and even chaotic. The outcomes of the system clearly show erratic oscillations and predict an undesired escalation of risk of strategic intercontinental nuclear war in the case of the development of SDI. They confirmed that, in the political science field, the transition from predictability to chaos in deterministic mathematical system is possible.

11. Political Parties and Elections

Using elections results, quarterly, monthly and even weekly polls, Weisberg (1998) observed, in a particularly original application of the chaos theory into political science, that the more frequent the measure, the greater change is found. The work on *fractals* in the chaos theory provides an important insight on measuring electoral change. According to the chaos theory, scale is important when dealing with some objects. One can measure more irregularities with a smaller unit of measure, and these irregularities add to the overall length. The fractal geometry suggests a parallel result for measuring change over time in political science. As a result more electoral change was found when measuring changes across shorter time periods. In addition, chaos theory suggests that nonlinear change can also be relevant in politics (Brown, 1996). The main findings concerning electoral change confirm the linearity of vote intention in elections, but some small events during the campaign can be responsible for larger changes. On the long-term, chaos renders predictions about politics impossible. As a result, one can say that electoral time should be recognized to be discontinuous, the amount of change found in a time-series should be understood to depend on the frequency of measurements, the importance of nonlinear change should be recognized, and electoral series should be expected to be always changing (Weisberg, 1998).

The chaos theory can also be applied for political actors, and political parties in particular. In a work still in progress, Plaza i Font (2006) tackled the organizational change of the European Popular Party (EPP), paying special attention to the ideological evolution of the party. With the arrival of new member parties in 1991 because of many institutional and also internal reasons, the EPP completely changes his ideological realignments. So, despite of coming from a strict classical Christian democratic tradition, the present EPP amalgamates many different national parties with no ideological homogeneity, representing Christian democrats, and even liberal or conservative traditions. This phenomenon was firstly modelled as a “chaotic ideological system”. Hence it permitted to describe an “ideological trajectory” of the evolution within the EPP and, consequently, analysing the arrival of those new member parties to the EPP as a bifurcation point leading the system to states of minor ideological order (major disorder).

12. Political Systems

Finally, rather than focusing on a particular topic, organisation or public policy field, few authors studied political systems as a whole. A significant exception concerns the Arab world where the Gulf war was considered as having introduced chaos in the Arab political system (Ismael & Ismael, 1993). The political situation after the war was assessed as volatile and unpredictable and small changes or fluctuations could easily produce large and turbulent changes, driving Arab politics in unexpected directions. The war destabilised this system and several bifurcations have been identified like the social world oscillating between traditional patterns of stratification and modern patterns of power, privilege and influence, or like the political world oscillating between an internal sphere where struggles of power are not soften by cultural norms and an external sphere where such struggles are bounded by cultural norms. As a result, the Arab state system was considered as a system with high sensitive dependence on initial conditions and where the trajectories of this system are no longer predictable. The turbulences that resulted from the war will increase but one cannot assess whether it would only be short-term turbulences or long-term chaos.

The chaos theory also provided metaphors – in particular the dissipative structures – to observe the Belgian political system. Based on the Dutroux-case (a paedophile committing several crimes), Lippens (1998) stated that this case could be read as a attractor which was strangely attracted around empty signifiers, as a collector of the people's discontent. During the investigation, the forces of order (as the police) that are supposed to be the guardians of the stability were considered as having generated chaos in the Belgian society, and more precisely in the political and societal system. In addition, the 'spaghetti' episode of the investigation was considered as close to the butterfly effect as some media talked about a Belgium "pre-revolutionary" climate as the results of these small events. Similarly, the whole Belgian political system has always been considered as quite 'unstable' over time (cabinet's instability, fragmentation and bifurcation of the party system, electoral turnover, and internal ethno-linguistic conflict), showing an irregular pattern and being assessed as unpredictable. Dandoy (2000) used empirical data for these four political dimensions. Using the Fourier transform, the author observed that the governmental, partisan and electoral dimensions are all driven by the long-term perspective, probably explained by larger and sociological considerations. They allow little space for any attempt of short-term prediction. However, as far as the ethno-linguistic dimension is concerned, the results show a continuous spectrum meaning that the system seems to be chaotic. The instability of the Belgian political system should therefore be apprehended in two-ways: as a long-term dynamic behaviour as far as cabinets, parties and elections are concerned, and as a chaotic behaviour as far as the ethno-linguistic conflict between Flemish and French-speakers is concerned. It is probably the conjunction of both behaviours that makes predictions about the future of the whole Belgian system and its survival quite limited.

13. Conclusion

Beyond the epistemological debate between order and disorder and the one about prediction and irreversibility, this paper intended to explore the new tracks opened by the so-called chaos theory in social science, and more particularly in political science. The chaos has been defined as a dynamic system showing a deterministic complex behaviour, irregular and non-periodic with random appearance but maintaining a latent order. Even if the path of the chaos is not leading to a whole new paradigm in social sciences, it still shows a large potential for useful reflexions and applications.

Firstly, this theory has been mainly applied as a metaphor for description and analysis. The rhetoric and the semantic of the chaos brought with it a bunch of new concepts and terms particularly useful for the understanding of political phenomena, like bifurcation points, sensitivity to initial conditions, auto-similarity, oscillations, dissipative structures or even entropy. This new vocabulary allows the researcher to develop his/her knowledge and explore new aspects of the observed social and political phenomenon.

In addition and mainly applied in the fields of public policy and sociology of organisations, it introduced a more quantitative approach. The chaos theory delivers new tools and methods for the researcher that, based on longitudinal data, intends to analyse graphically the evolution of dynamic political systems. These graphic-based tools are quite diverse, going from the phase space attractors to the fractals and the spectral analysis and can provide useful complements to the more traditional scientific tools. More globally, the innovative aspects of the chaotic perspective show a promising scientific potential for analysing and describing the time-based evolution of public policies and political institutions, actors and processes like election cycles.

References

Bergé, Pierre & Dubois, Monique (1992), "Chaos déterministe expérimental et attracteurs étranges », *Chaos et déterminisme*, Ed. du Seuil, Paris, pp. 115-169.

Betts, Richard K. (2000) "Is strategy an illusion?", *International Security*, vol. 25, n° 2, autumn, pp. 5-50.

Beyerchen, Alan (1992) "Clausewitz, nonlinearity and the unpredictability of war", *International Security*, vol. 17, n° 3, Winter.

Bird, R. J. (1997) "Chaos and social reality: An emergent perspective", Raymond Eve, Horfshall Sara and Lee Mary M. (ed.) *Chaos, complexity and sociology*, Sage Pub., London, pp. 141-152.

Brown, Courtney (1994) "Politics and the environment: Nonlinear instabilities dominate", *American Political Science Review*, June, vol. 88 (2), pp. 292-303.

Brown, Courtney (1995) *Chaos and Catatrophe Theories*. London: Sage Publications.

Brown, Thad A. (1996) "Nonlinear politics", Kiel Douglas L., Elliot E. (Eds.) *Chaos Theory in the Social Sciences*, University of Michigan Press, Ann Harbor, pp. 119-137.

Byrne, David (1998) *Complexity Theory and the Social Sciences*. London: Routledge.

Capra, Fritjof (1996) *The web of life: a new scientific understanding of living systems*. New York : Anchor Books.

Chernus, Ira (1993) "Order and disorder in the definition of peace", *Peace & Change*, vol. 18, n° 2, April, pp. 99-125.

Dahan-Dalmédico, Amy ; Chabert, Jean-Luc and Chemla, Karine (1992) *Chaos et déterminisme*, Ed. du Seuil, Paris.

Dandoy, Régis (2000) *Chaologie et sciences politiques. L'instabilité du système politique belge*, Master thesis, University of Louvain (UCL).

Geyer, Robert (2003) "Europeanization, Complexity and the British Welfare State". Paper presented to the UACES/ESRC Study Group on The Europeanization of British Politics and Policy-Making, Department of Politics, University of Sheffield, September 19th.

Gleick, James (1987) *Chaos*. New York: The Viking Press.

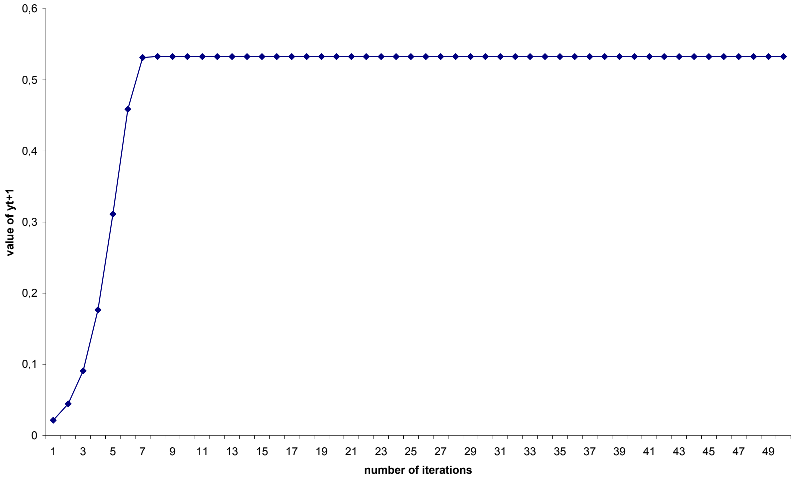
Enders, Walter and Sandler, Todd (2002) "Patterns of transnational terrorism, 1970-1999: Alternative time-series estimates", *International Studies Quarterly*, vol. 46, pp. 145-165.

Farazmand, Ali (2003) "Chaos and transformation theories: A theoretical analysis with implications for organization theory and public management", *Public Organization*, vol. 3, December, pp. 339-372.
Galtung, Johan (1975) "Entropy and the general theory of peace", *Peace: Research Education Action, Essays in Peace Research*, vol. 1, Copenhagen.
Herman, Jacques J. (1994) "Chaologie, Politique et Nationalisme". *Revue Internationale De Politique Comparée,* 1 (3):385-415.
Ismael, Tareq Y. and Ismael, Jacqueline S. (1993) "Arab politics and the Gulf war: Political opinion and political culture", *Arab Studies Quarterly*, vol. 15, n° 1, Winter.
Jong, Heon Byeon (1999) "Non-Equilibrium Thermodynamic Approach to Change in Political Systems." System Research and Behavioural Science 16 (3):283-291.
Kiel, Douglas L. (1989) "Nonequilibrium theory and its implication for public administration", *Public Administration Review*, Nov-Dec, pp. 544-551.
Kiel, Douglas L. (1993) "Nonlinear dynamical analysis: Assessing systems concepts in a government agency", *Public Administration Review*, March/April, vol. 53 (2), pp. 143-153.
Kiel, Douglas L. (1994) *Managing chaos and complexity in government: A new paradigm for managing change, innovation and organizational renewal*, Jossey-Bass Pub., San Francisco.
Kiel, D. and Elliott, E. (1996) (eds.) *Chaos Theory in the Social Sciences*. Ann Arbour: The Michigan University Press.
Krasner, S. (1990) (ed.) *The Ubiquity of Chaos*. Washington DC. : American Association for the Advancement of Science.
Laplace, Pierre-Simon (1951 [1814]) *A Philosophical Essai on Probabilities*. New York: Dover. (Original Title: Essai philosophique sur les probabilités).
Laszlo, Erwin (1990) *La Grande Bifurcation*. Paris: Tacor International.
Lewin, Roger (1992) Complexity: life at the edge of chaos. New York: MacMillan.
Lippens, Ronnie (1998) "The white march as a Belgian body without organs: On dissipative structures, strange attractors and empty signifiers", *Crime, Law and Social Change*, Kluwer, vol. 29, pp. 49-65.
Lorenz, Edward (1993). *The Essence of Chaos*. Washington D.C.: University of Washington Press.
Martín, Miguel Ángel; Morán, Manuel and Reyes, Miguel (1995) *Iniciación al caos. Sistemas dinámicos*. Madrid: Editorial Síntesis.
McBurnett, M. (1996) "Probing the Underlying Structure in Dynamical Systems: An Introduction to Spectral Analysis." pp. 165-198 in Chaos Theory in the Social Sciences, edited by D. Kiel, and E. Elliott. Ann Arbour: The University of Michigan Press.
Mesjaz, Czeslaw (1988) "Systems modelling in Peace research", *Journal of Peace Research*, vol. 25.
Ortega y Gasset, José (2001 [1941]) La historia como sistema. Madrid: Biblioteca Nueva.
Peled, Alon (2000) "The New Sciences, Self-organization and Democracy", *Democratization*, vol. 7, n° 2, Summer, pp. 19-35.
Plaza i Font, Joan Pere (2006) *Dinámicas no-lineales en partidos políticos. El caso del Partido Popular Europeo*, Master thesis, University of Barcelona (UAB) & University of Louvain (UCL)

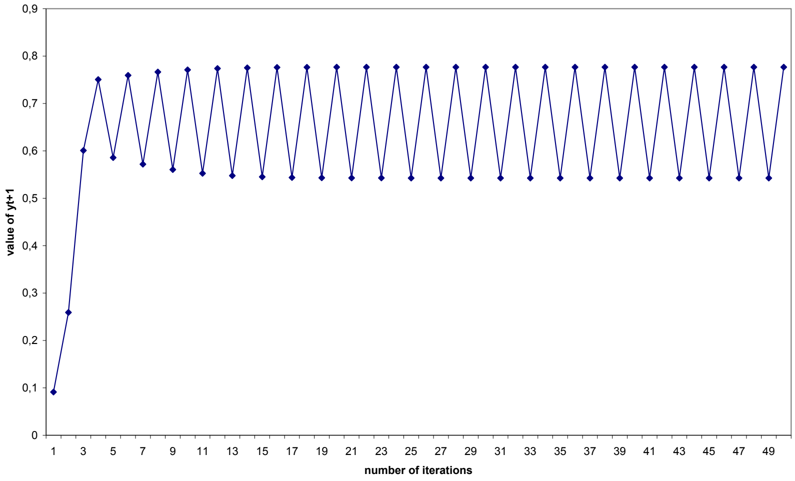
Pierson, Paul (2000) “Increasing Returns, Path Dependence and the Study of Politics”. *American Political Science Review*, 94 (2): 251-267.
Prigogine, Ilya (1993) *Les Lois du chaos.* Paris: Flammarion.
Prigogine, Ilya and Nicolis, G. (1989) *Exploring complexity : an introduction*. New York : W.H. Freeman and Company.
Prigogine, Ilya and Stenglers, Isabelle (1984) *Order out of chaos*. Boulder (CO, USA): New Science Library.
Radu, Michael (2000) “Festina Lente: United States and Cuba after Castro. What the experience in Eastern Europe suggests. Probable realities and recommendations”, *Studies in Comparative International Development*, vol. 34, n° 4, Winter, pp. 7-22.
Ruelle, David (1991) *Hasard and Chaos*. Princeton : Princeton University Press.
Saperstein, Alvin M. & Mayer-Kress, Gottfried (1988) “A nonlinear dynamical model of the impact of SDI on the arms race”, *Journal of Conflict Resolution*, December, vol. 32 (4), pp. 636-670.
Sinaï, Yakov G. (1992) “L’aléatoire du non-aléatoire”, *Chaos et déterminisme*, Ed. du Seuil, Paris, pp. 68-87 .
Steward, Ian (1992) *Dieu joue-t-il aux dés ? Les nouvelles mathématiques du chaos*, Flammarion, Paris.
Stroup, William F. (1997) “Webs of chaos : Implication for research designs”, *Chaos, complexity and sociology*, Sage Pub., London, pp. 125-140.
Weisberg, Herbert F. (1998) “Nonlinear models of electoral change: The implications of political time and chaos theory for the study of mass political behaviour”, *Electoral Studies*, vol. 17 (3), pp. 369-382.
Zuckerman, Alan S. (1997) "Reformulating explanatory standards and advancing in comparative politics", en: M.I. Lichabach and A.S. Zuckerman. *Comparative politics: rationality, Culture and Structure*. New York: Cambridge University Press.

Appendix

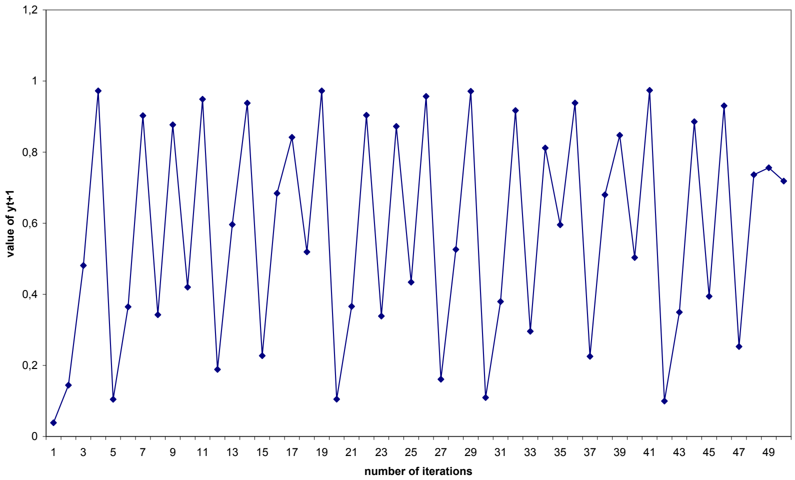
Graph 1: data for y = 0,99 and w = 2,14



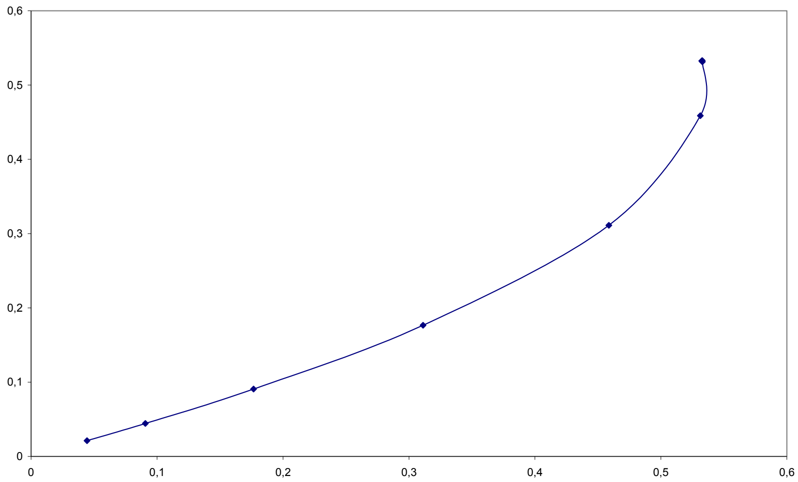
Graph 2: data for y = 0,97 and w = 3,13



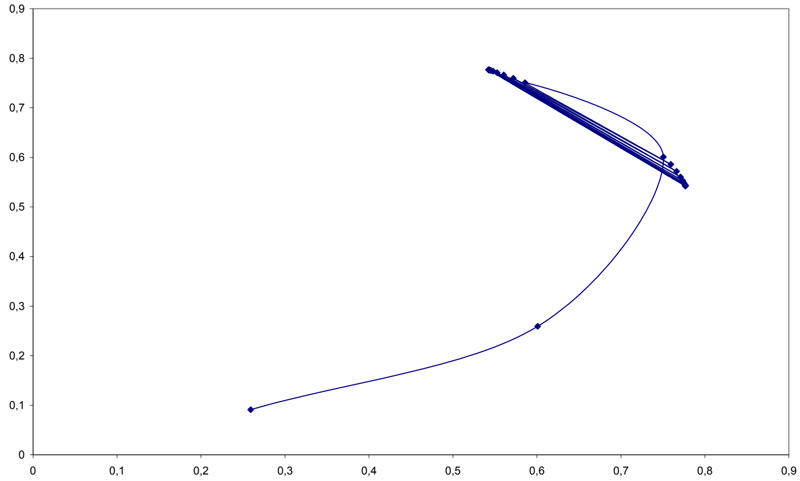
Graph 3: data for y = 0,99 and w = 3,895



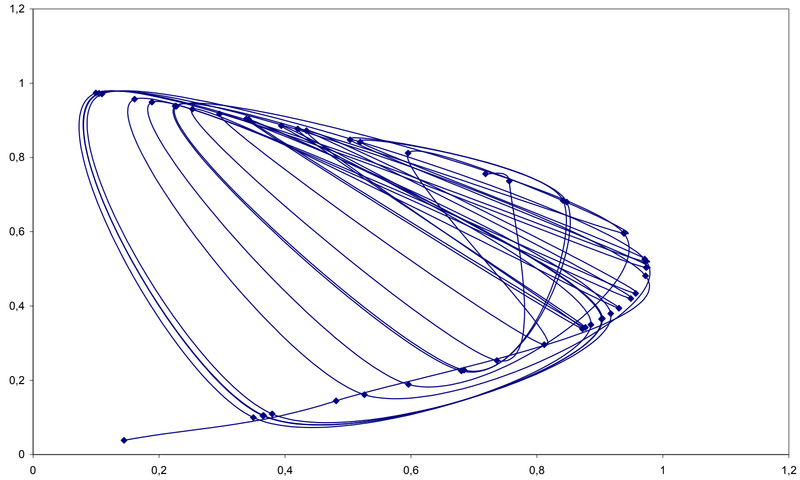
Graph 4: Punctual attractor



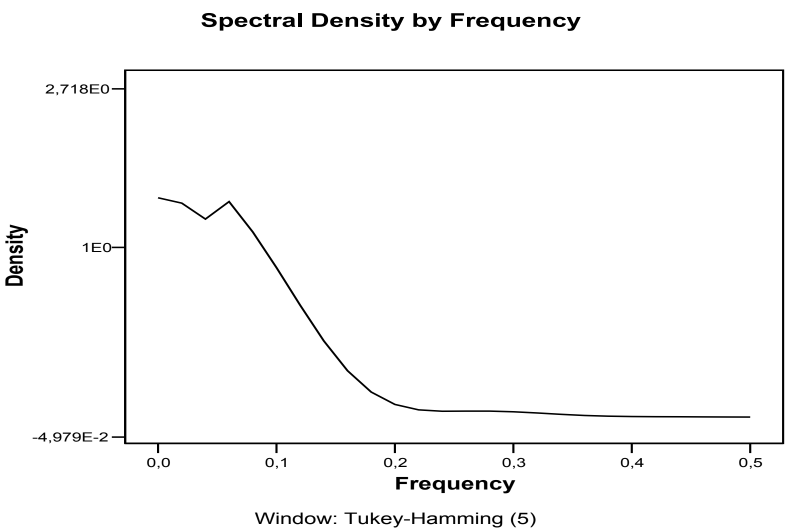
Graph 5: Periodical attractor



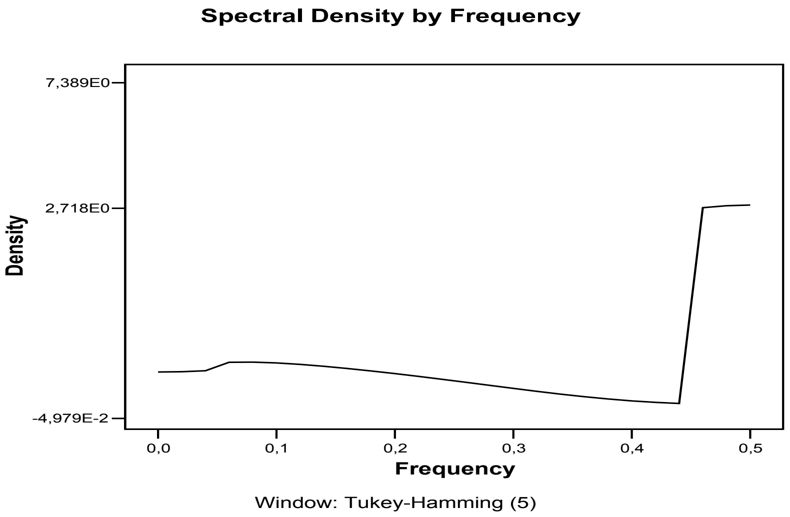
Graph 6: Strange attractor



Graph 7: Spectrum of a constant system



Graph 8: Spectrum of a periodic system



Graph 9: Spectrum of a chaotic system