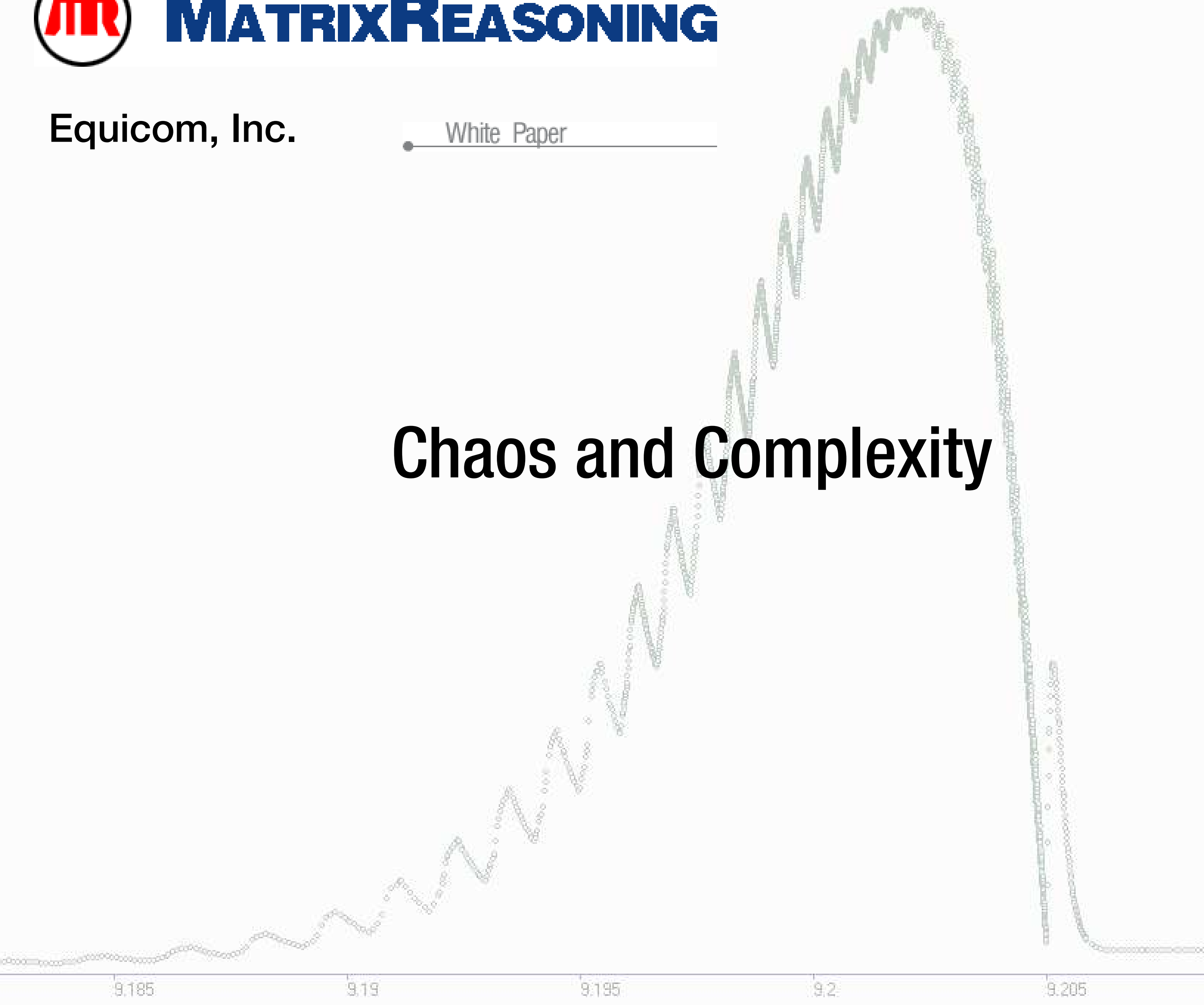
MATRIXREASONING

Equicom, Inc.

White Paper

Chaos and Complexity



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Introduction

Analysis of complexity in complex systems and the establishing of regularities of the emergence of the state of chaos is a universal problem that is relevant in all fields of science, and crucial in many areas of human activities involving critical situations in the context of Nature's processes, as well as social and technological issues. Despite the intense interest in this topic, especially active since the 1960's, and numerous publications on chaos, there is a wide gap between theoretical postulates on chaos and complexity and the real capability of practical application of such knowledge.

The gap between theory and practice in the problem of chaos is primarily caused by the absence of universal criteria for quantitative evaluation of complexity in complex systems. The next important challenge in analysis of complex systems of objects whose adequate description usually involves high-dimensional spaces of parameters is the development of reliable universal methodology that would provide organic fusion of parameters and setting the weights of parameters in accordance with their contribution into the effect produced by the totality of all parameters describing a given system. The third important requirement to an efficient method for analysis of chaos is the capability to process and analyze any system as informationally closed, which allows the analysis of interrelations between objects within a system, even between such objects that are not in direct contact with each other.

Below is a brief description of the approach and methodology developed by Equicom, which provide efficient solutions to the above-specified problems and represent a unique technology for analysis of complexity in complex systems, including the states of generalized complexity resulting in chaos within a system under analysis. It is demonstrated that the dynamics of chaos has a universal pattern and, as a rule, is accompanied by a release of the "energy of chaos", manifested in a powerful reversible antichaotic reaction of the system. Each system has its own limit of the "energy of chaos" that it can accumulate. We propose to differentiate between two types of order in a system: nonchaotic and antichaotic. This approach provides new opportunities in computer simulation of extremely complex processes, such as stock market performance, seismic events and their causes, atmospheric processes leading to tornado formation, cosmological events and many other phenomena.

Main components of the technology for analysis of complexity and chaos

Practical realization of the subject technology has become possible due to a series of methodological solutions developed at Equicom and covered by a U.S. Patent, pending patents and patent applications in process, including the following original innovative methods and techniques:

1. An algorithm for evolutionary transformation of similarity matrices (ETSM) which provides automated unsupervised hierarchical clustering [1]. The ETSM algorithm processes any system as informationally closed and, through the so-called bifocal compression process, renders it into two points with coordinates of 1 and 0, respectively, in the space of similarities. The dynamics of ETSM is expressly non-linear, which provides a non-linear logic of clustering [2]. The ETSM algorithm represents a fundamentally new approach to information processing; it is self-intelligent and multiprocessor-friendly.
2. A special 'contrasting' algorithm that allows the data processing within extremely wide range similarity coefficients [1].
3. Two universal metrics specially designed for the ETSM algorithm, which are used for processing of 'shape' and 'power' parameters [3].
4. A method providing the continuous changing of parameter weights in the process of similarity matrix computation by hybridization of monomer similarity matrices based on each individual parameter [3].
5. Cluster spectroscopy, which provides visualization and quantitative evaluation of bifocal compression of data [4].
6. A cluster spectroscopy-based criterion of system complexity defining the 'egoentropy' of a system under analysis [5]. Egoentropy is complementary to classical entropy, and unlike the latter, it can be applied in analysis of any systems, starting from the molecular level, up to the global systems. The principle of egoentropy is based on summation of information on how much each object of a given system is separable from the rest of the objects.

Our approach to analysis of chaos in a community of data points involves the measurement of the system's egoentropy as a measure of disorder in the course of the continuous changing of the weights (dimensions) of individual parameters or combinations of parameters. This provides the registration of all changes occurring in the system's complexity, including the emergence of the state of chaos. The emergence of a chaotic state is manifested in the form of chaotic spikes, whose number and positions are specific in any concrete system under analysis and therefore represent its unique characteristic. MeaningFinder 2.2 allows manual operations for obtaining and analysis of chaotic spikes in low to medium complexity systems.

Fractal character of parameter dimensions

A genial generalization on the fractal character of the geometry of Nature, made about 30 years ago by an IBM Fellow Benoit Mandelbrot has been a truly fundamental discovery with unique implications for science and technology. However, the application potential of this conception has not yet been fully realized, and fractal geometry mostly serves as inspiration for fractal art and publications on self-organization and self-copying, with invariable pictures of fern, spruce and broccoli. The main cause of the problems in practical implementation of these ideas lies in the lack of understanding of how, in fact, fractality of parameters that determine our perception and description of the environment is realized and why and how it is changing.

However strange it may sound, the most complex phenomenon in Nature – human mentality – is the most self-explanatory example of manifestation of dimension fractality. When you respond to a poll question: “Will you vote for: a) X; b) Y; c) none of the above?”, you are forced to express your opinion in integer dimensions – despite that your opinion on X and Y may be more complex: you may like X in principle but dislike some of his/her relevant features, and you dislike Y in general but like some of his/her relevant features. Thus, this question (which is one of parameters of the poll) can be presented as a totality of sub-parameters with different dimensions that can vary from 0 to 1, wherein “1” represents a definitive “yes” or “no” opinion. How a respondent’s subconscious processes those sub-parameters and weighs the resulting decisions, we do not know. But it is clear that a “yes” or “no” answer to a question of this type is a rounded reflection of an opinion that has an expressly fractal structure.

Assume that in this hypothetical poll, numbers of votes for X and Y appeared to be equal. This creates instability in the system, as any slightest fluctuations in sub-parameter dimensions can result in dramatic shifts in the overall situation. Let us consider a more specific example based on a real-life public opinion poll on gun control laws, conducted by The Los Angeles Times National Poll (Study # 443, July 31, 2000). Having analyzed the egoentropy of the resulting system of data points, we established that at a certain point in the course of variations in dimension values of one of the poll parameters from 0 to 1, there emerges a chaotic spike whose maximum height point corresponds to the egoentropy level that is 220 times higher than the system’s normal, and that the width of the spike’s base equals an infinitesimal fraction $9 \cdot 10^{-4}$ of the parameter’s dimension value [6]. The point of emergence of the chaotic spike corresponds to the point at which, as a result of the continuous changing the parameters’ dimensions, the system reached the state of equilibrium in terms of respondents’ opinions. Figures 1A and 1B illustrate the chaotic spike and its detailed anatomy. As is seen in Fig. 1B, the chaotic spike has a peculiar structure: when it is close to reaching its maximum, it transforms into the inverse spike almost reaching the zero line and ascending again to the maximum point.

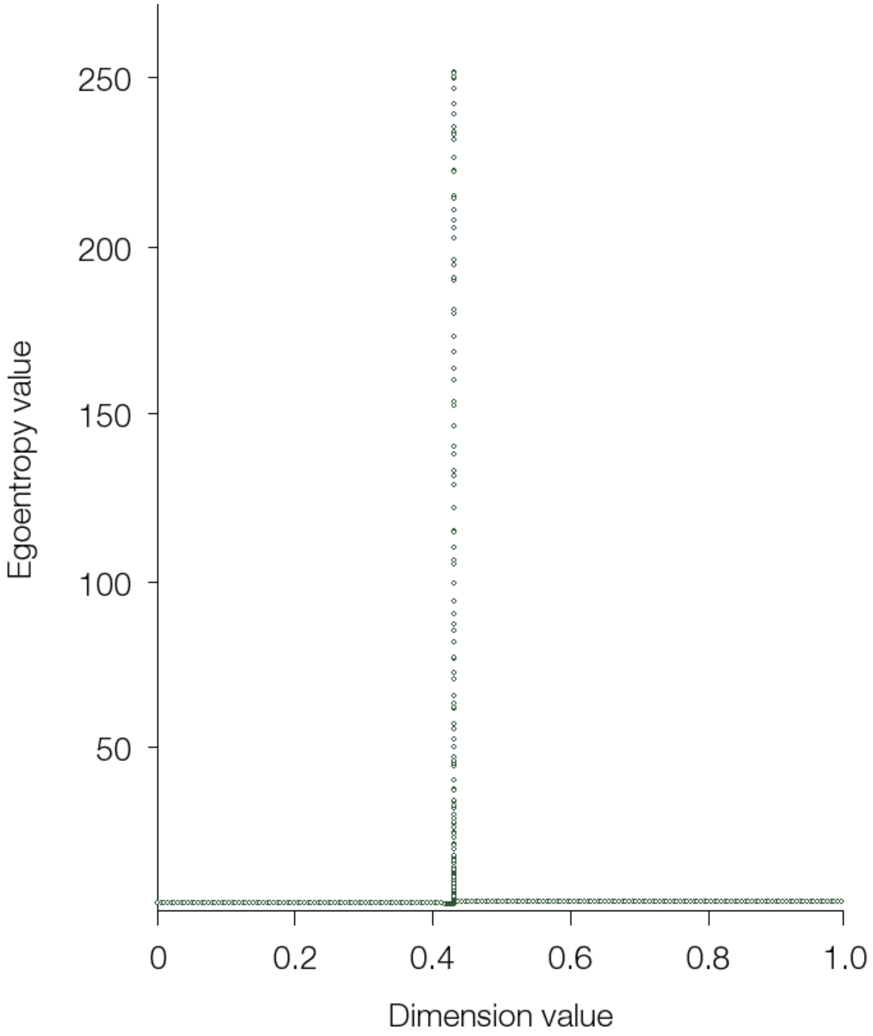


Figure 1A. Chaotic spike emerging in the course of changing the dimension value of one of the parameters of the public opinion poll from 0 to 1.

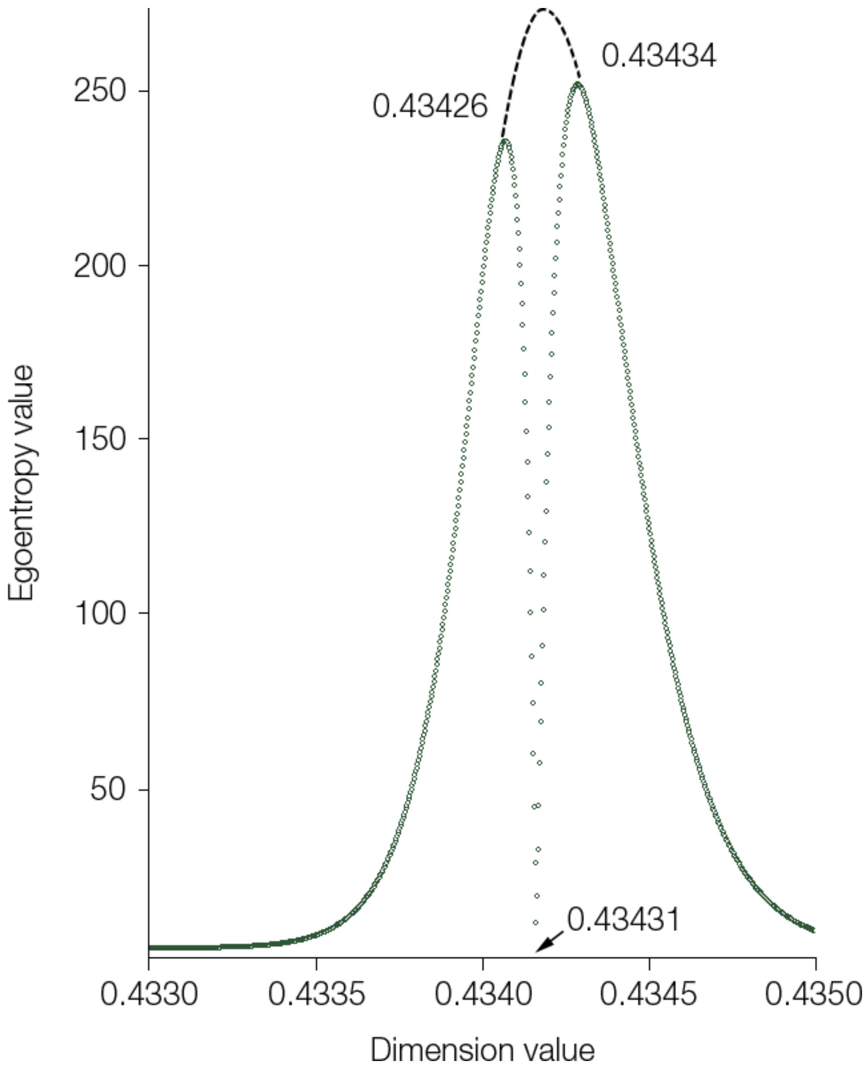
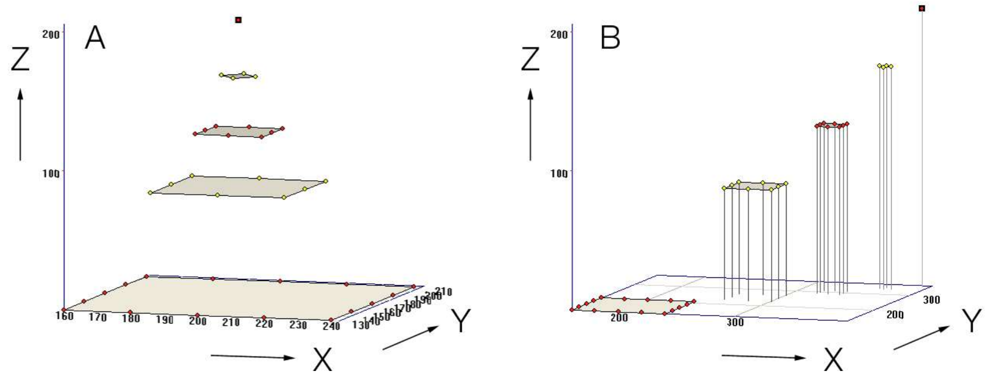


Figure 1B. Same chaotic spike as in Fig. 1, registered at the DV scale 500:1. The black dotted part of the curve is the hypothetical trajectory of the chaotic spike in the absence of the antichaotic spike.

Universal pattern of chaotic spikes

Our methodology allows the analysis of systems of any degree of complexity, presented as both structured and unstructured data in binary and/or numerical form, involving unlimited number of parameters describing the objects within a system under analysis. We experimentally established that the above-demonstrated structure of chaotic spikes (Figure 1B) is universal and, with very rare exceptions (discussed in a following section of this report) does not depend of specifics of systems under study. As this fact is crucially important, we will now refer to one more example based on a different kind of data.

Figure 2A illustrates a 3D geometric structure representing a result of ETSM-based clustering and showing five levels of subclusters (each shaded area corresponds to a subcluster). The changing of the dimension values (DV) of parameter X (or Y) results in the emergence of two



Figures 2A – 2B. 3D diagrams of a system of scattered points.

Chaotic spikes, at DV of 3.820 and 4.906, respectively (Figure 3). The changing of parameter Z dimension value from 1 to 100 does not cause the emergence of chaos. Obviously, the underlying cause of the emergence of chaotic spikes is such a state of the system when, as a result of certain combinations of parameters' dimensions, some of the objects are no longer differentiated. As in this system there are hiatuses along axis Z, the changes in the Z dimension do not affect the system's order and therefore no chaotic situations emerge upon fluctuations in this parameter's dimension. This conclusion is supported by the result illustrated in Figure 2B: here, the subclusters are shifted relative to each other so as they are separated from each other by hiatuses, i.e.

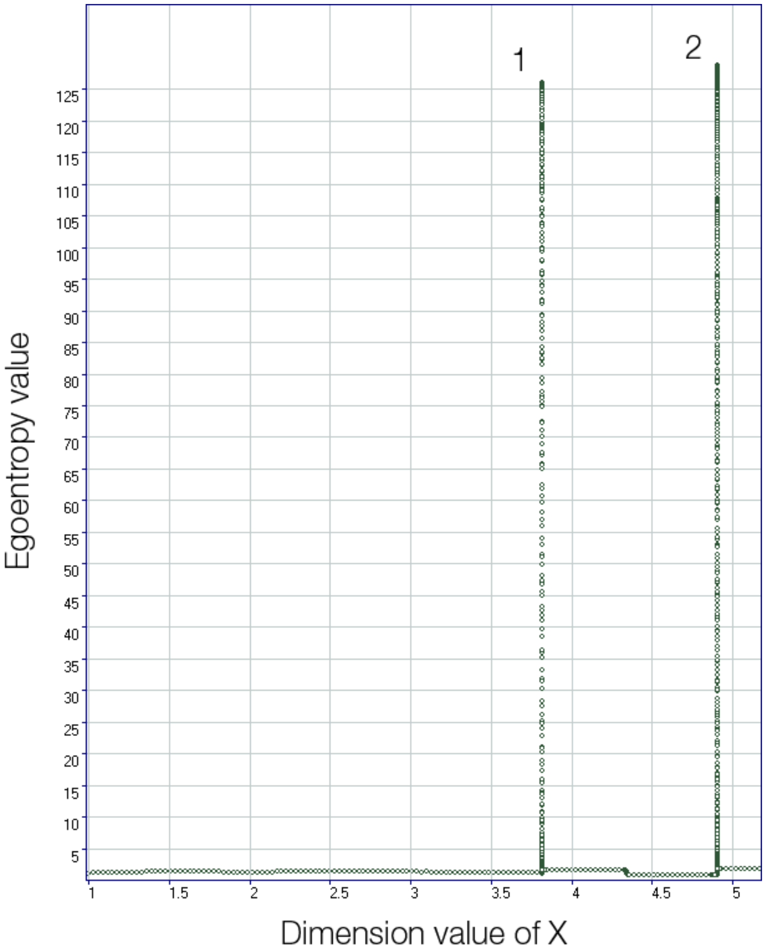


Figure 3. Chaotic spikes emerging in the course of changing the dimension value of X parameter of the system of scattered points shown in Figure 2A.

they do not overlap in the X-direction, and therefore the changes in the X parameter dimension do not cause the emergence of chaotic spikes.

Constancy of egoentropy maximum (E_{max})

Egoentropy is a complexity criterion that adequately reflects the changes in a system's complexity. This is convincingly demonstrated by the fact that the maximum egoentropy level (E_{max}) that can be reached by a system upon changes in dimensions of any of its parameters is always constant and specific for a given system. For instance, as is seen by comparison of the chaotic spikes shown Figures 1B and 4A – 4B, the E_{max} values of these systems differ by two times, which shows that each system has its own specific limit of potential disorder.

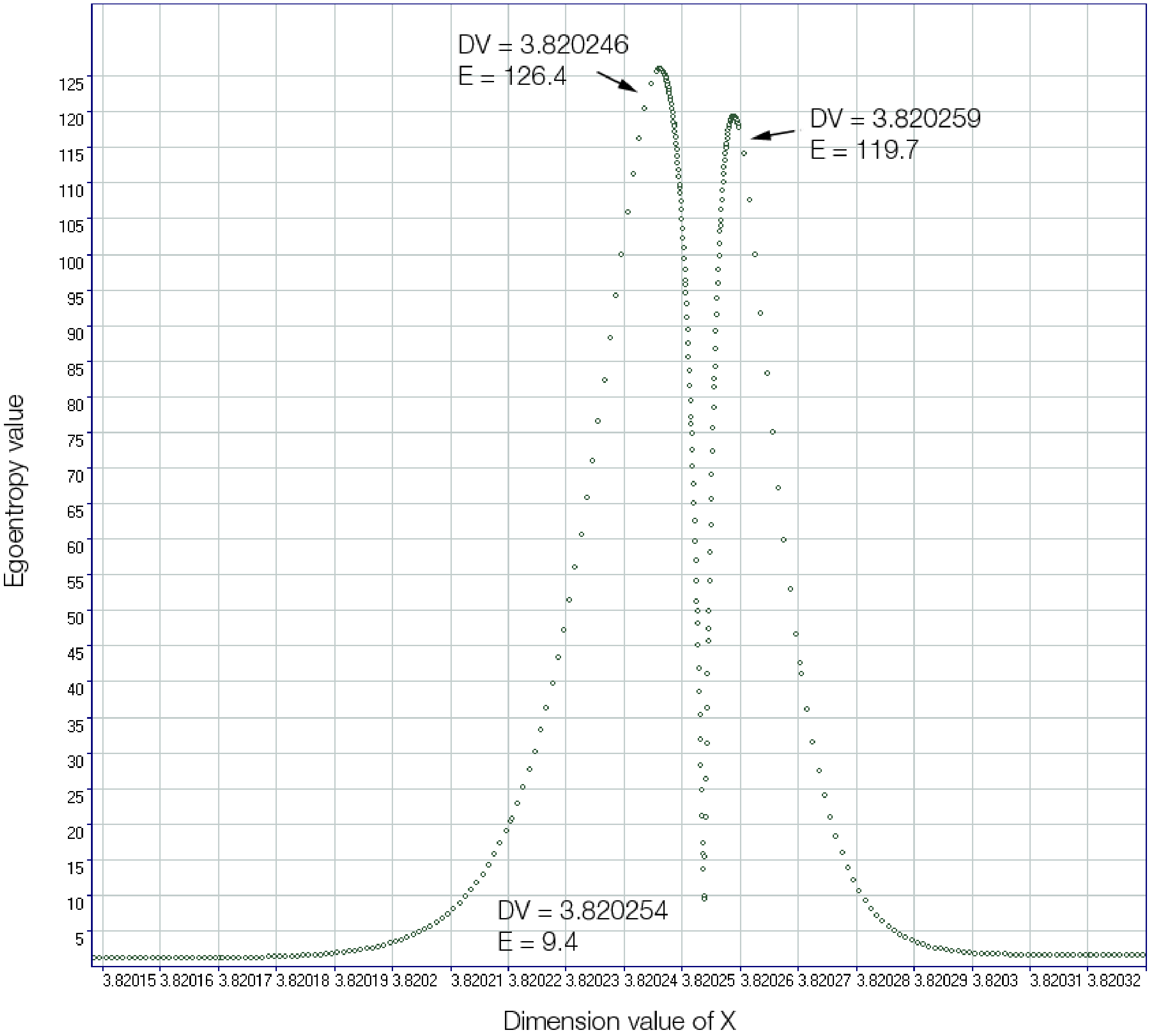


Figure 4A. A detailed view of chaotic spike No. 1 of Figure 3

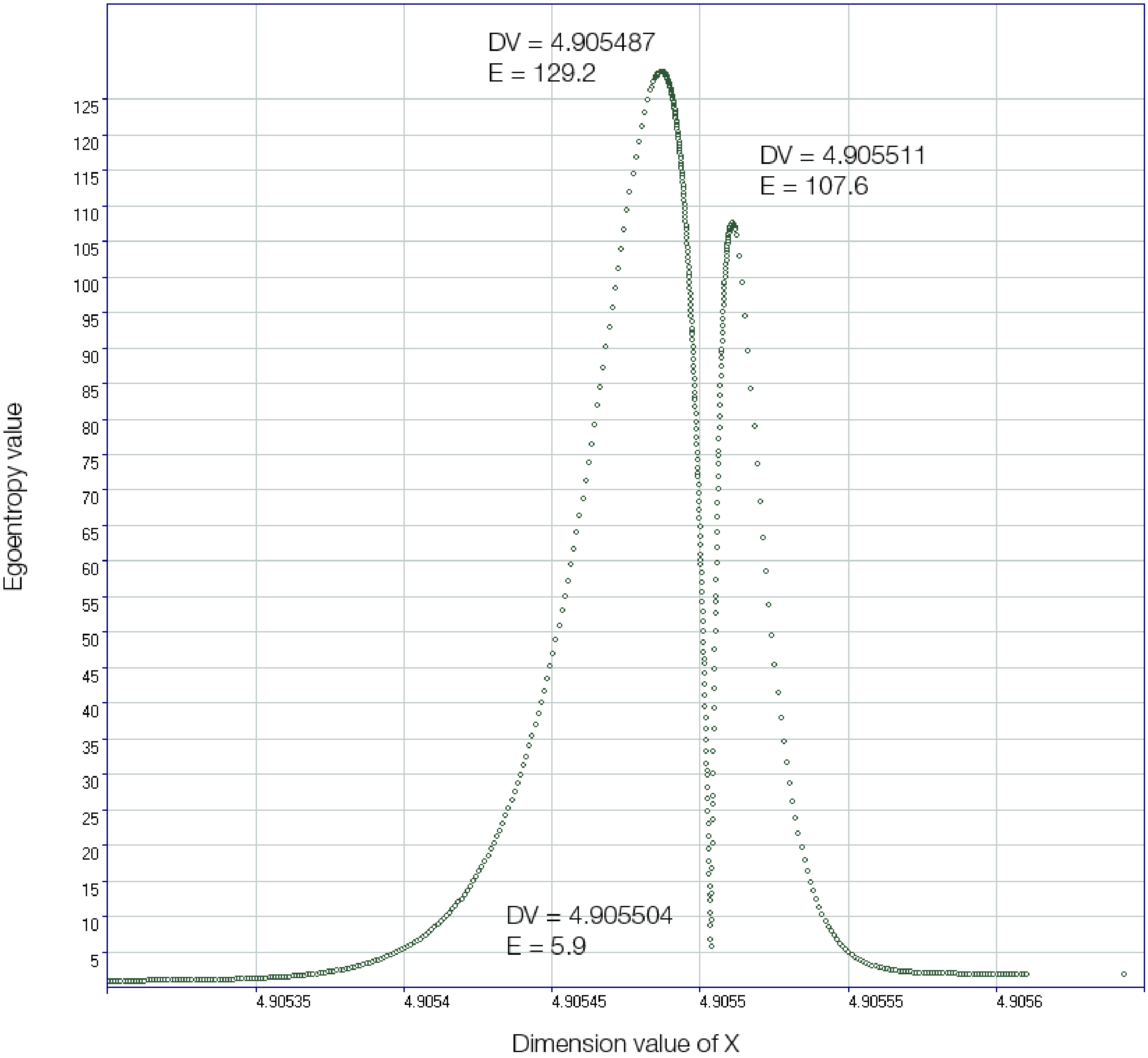


Figure 4B. A detailed view of chaotic spike No. 2 of Figure 3

Exceptions from the typical chaotic spike structure

We have studied the emergence and structure of hundreds of chaotic spikes in various systems and, as was mentioned above, established that the chaotic spike shape is generally invariable: at egoentropy values close to maximum, the chaotic spike produces a narrow inverse spike ('anti-spike') that instantly reaches the extremum indicating the system's return to initial egoentropy level, after which it again quickly ascends to the peak of chaos. We have observed only a few exceptions, one of which, illustrated by Figure 5, is discussed below.

The chaotic spike shown in Figure 5 was obtained in the study of comparative climatic data on normal daily minimum and maximum temperatures for each month of the year, based on multi-year average, for 32 U.S. cities.

The continuous changing of dimension values from 1 to 10 for each individual city resulted in either non-emergence or emergence of several chaotic spikes. All registered chaotic spikes, except the one corresponding to Sacramento, CA, appeared to have the shape as illustrated in Figure 1B. In case of Sacramento, the chaotic spike's ascending and descending curves are sinusoids whose amplitudes are changing according to a complex pattern, and there is no inverse (antichaotic) spike in the area close to egoentropy maximum. As is seen in Figure 5, oscillations on the ascending curve reach the highest amplitude at the mid-part of the ascent, whereas the descending curve is made of fading oscillations that have maximal magnitude at the highest point of the chaotic peak and gradually damp out by the end of the descent, which is well seen in Figure 6 showing the final 15% stretch of the descending curve.

Remarkably, in case of Sacramento, there are three chaotic spikes (see Figure 7), and only one of them (No. 2) displays the self-oscillation process. Spike No. 1 in Figure 7, for instance, has the same ‘classical’ shape as illustrated in Figure 1B. The rate of changing of parameters’ dimensions does not have any effect on positions of maximum and minimum points of the spike shown in Figure 5.

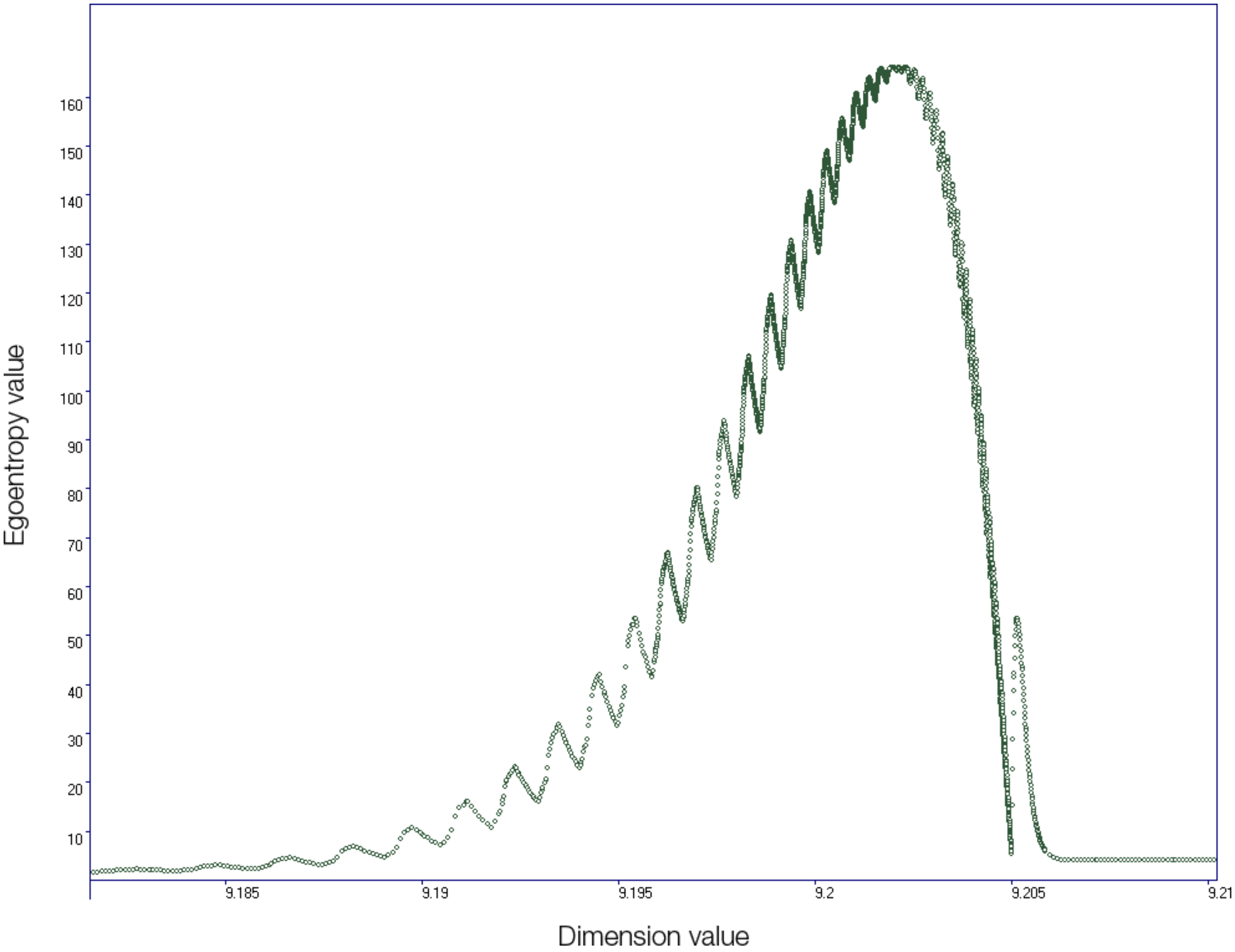


Figure 5. One of chaotic spikes of Sacramento. See details in the text.

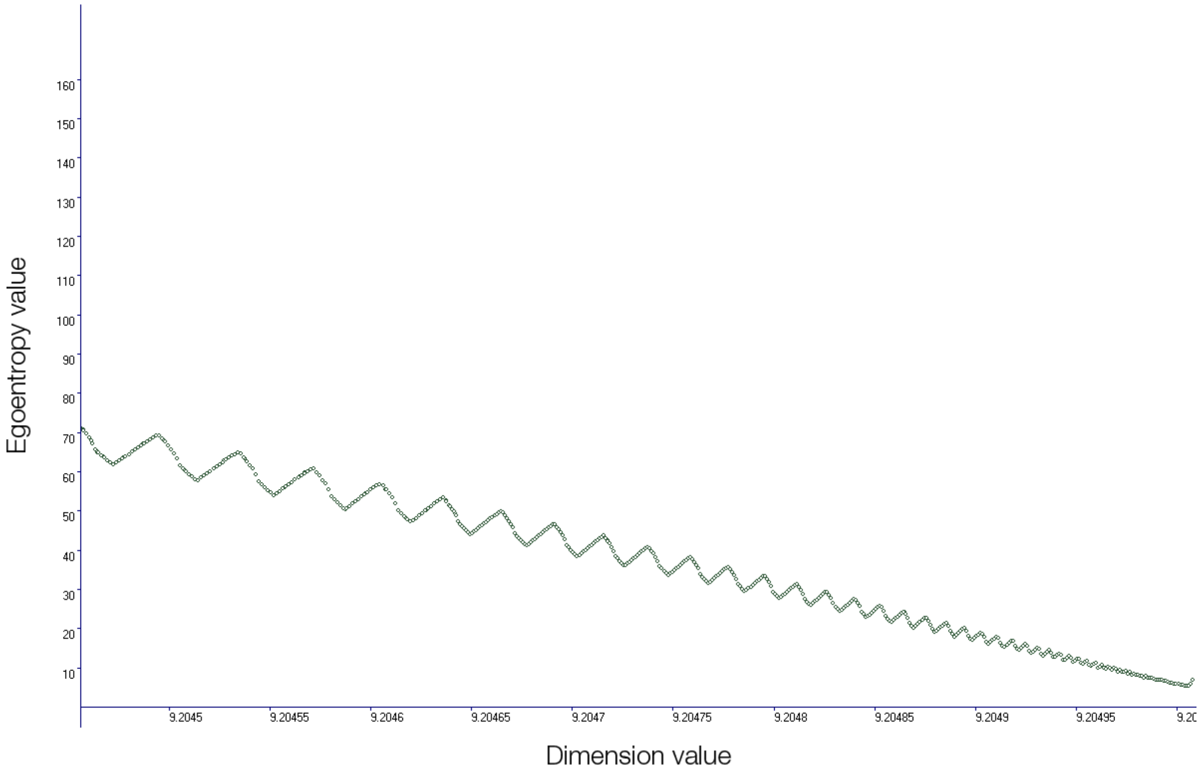


Figure 6. A detailed view of the final 15% stretch of the descending curve of the chaotic spike shown in Figure 5.

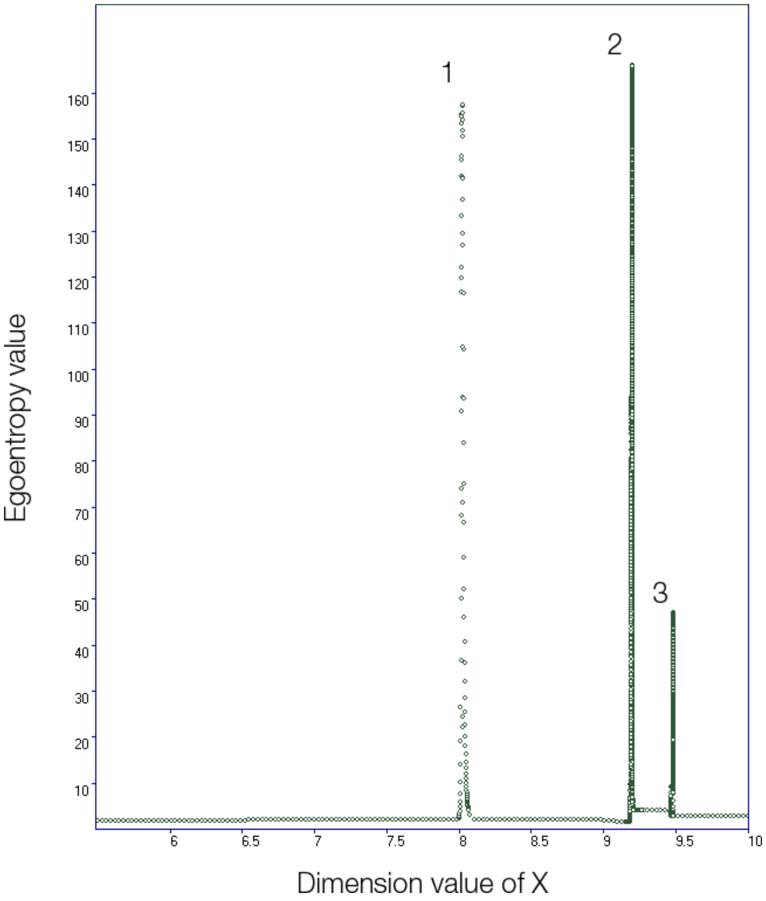


Figure 7. Entire chaotic spectrum of Sacramento. See details in the text.

Pre-chaotic complexity variations

Above, we described the new opportunities provided by our technology in the study of mechanisms of the emergence of chaos. A no less interesting area where our technology has a high application potential is the analysis of complex systems in the state of reversible regulation with no generalization of chaos. Below we demonstrate a solution for analysis of the impact of fluctuations upon complexity of symmetrical systems – we refer to the system of symmetrically positioned points illustrated in Figure 2A. For simplicity reasons, we removed the second from top subcluster and the bottom one, so the system consisted of the total of 17 points. Figure 8A shows the changes in the system's egoentropy upon variations of the X parameter dimension from 0 to 2: as is seen, the egoentropy curve is symmetrical relative to the point of DV=1. Even in this simple system, the changes in complexity have a very intricate pattern.

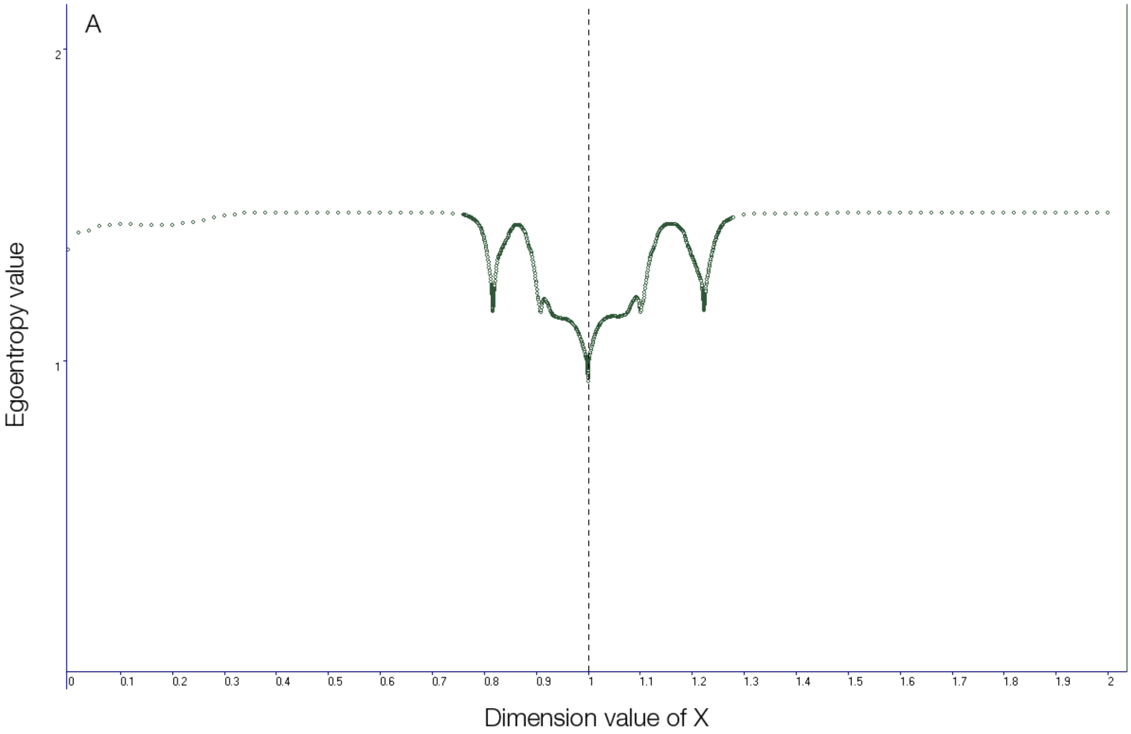


Figure 8A. Changes in egoentropy of a 3D system of 17 scattered points (see details in the text) in response to changes in dimension value of parameter X from 0 to 2.

Now we will increase by 0.5% the original value of the X-coordinate of the top point. As is seen from Figure 8B, the earlier observed symmetry of the egoentropy changes is no longer there, and the pattern of changes has become significantly more complex.

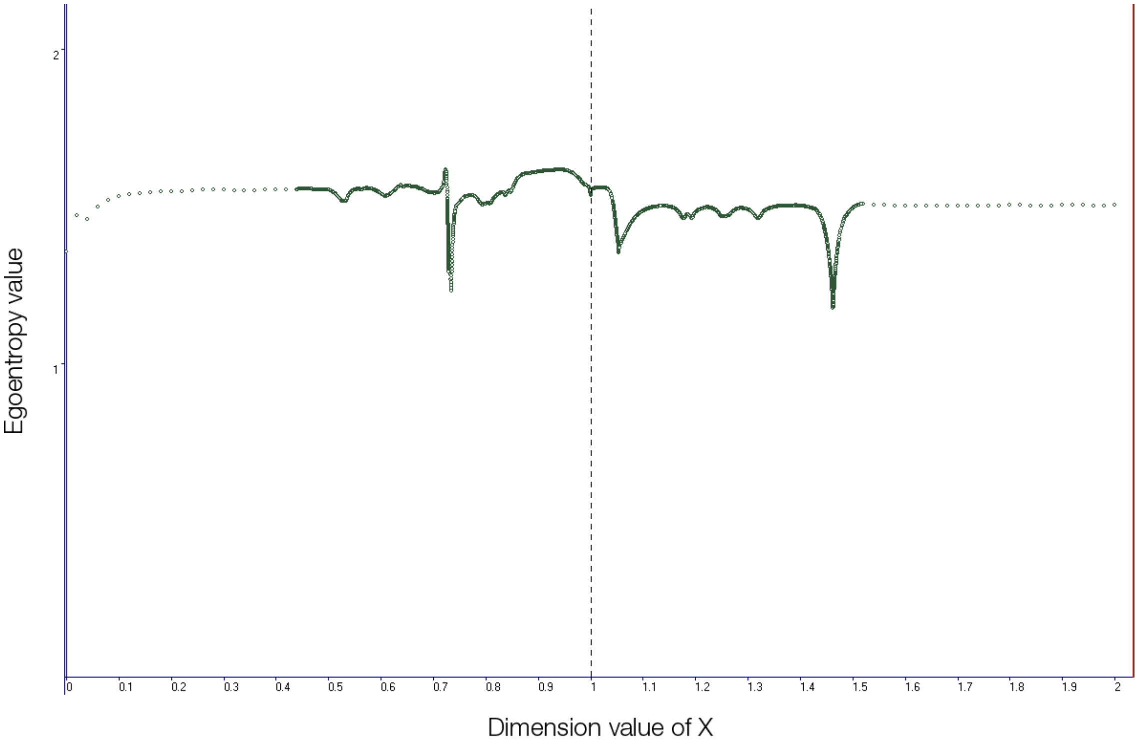


Figure 8B. Same as in Figure 8A but at an increased X-coordinate value of one of the points by 0.5%.

The original symmetrical pattern of the systems' egoentropy response was also significantly disturbed even upon a change as small as $5\cdot10^{-3}$ % of the parameter value of the same point. This example demonstrates the efficacy of our technology in precise identification of the elements of symmetry in complex systems.

Chaos and antichaos

As stated above, chaotic spikes emerging in systems undergoing changes in parameters' dimensions have a universal pattern. The number and positions of chaotic spikes in a system are unique: changes in dimensions of each individual parameter produce chaotic spikes at specific dimension values of that parameter. For instance, upon analysis of 75 countries by sex-age group distribution in their populations, the emergence of chaotic spikes was recorded at following dimension values of this parameter for: France, 12.2; Israel, 31.4; Russia, 43.2 and 44.4; Saudi Arabia, 9.0 and 25.5; Oman, 10.3; West Bank, 5.4 and 16; etc.

The same analysis was performed using the year 2000 data on population pyramids of newly independent countries formerly republics of the USSR. Chaotic spikes were observed to emerge at the following dimension values of the sex-age distribution parameter for: Russia, 4.87; Ukraine, 4.85; Belarus, 6.07; Lithuania, 6.87; Estonia, 4.97 and 5.68; Turkmenistan, 4.35; Kyrgyzstan, 3.71; Uzbekistan, 3.67; Tajikistan, 2.52; Azerbaijan, 3.51; Georgia, 7.36; Armenia, 7 spikes at DV varying from 20.84 to 23.68; etc.

Thus, the proposed technology provides unique capabilities in identification and classification of complex systems, as well as in the investigation of mechanisms of emergence of chaotic situations in complex systems. Both of these directions require fundamental R&D efforts for which our technology for analysis of chaotic situations offers valuable solutions. However, even the results of our prefatory work provide solid grounds for certain generalizations and prognoses. This concerns the afore-discussed discovery of the uniform constitution of chaotic spikes, which does not depend on a nature of a concrete system.

First of all, of special importance is the fact of the existence of a maximum limit of egoentropy in each given system, which has been rigorously proven by us by analysis of numerous systems. For instance, in a system described by 100 parameters, changes in the dimension of only one parameter may allow the recording of about 400 chaotic spikes, and a lot more chaotic spikes can result from concurrent changes in dimensions of more than one parameter. However, in none of the analyzed systems, did the egoentropy level ever exceed the E_{max} of a given system. As soon as the egoentropy level reaches the system's E_{max}, the chaotic spike collapses into the inverse spike. As is seen from the detailed view of the chaotic spike structure illustrated in Figures 1B and 4A – 4B, the dynamics of chaos develops as if it is "unaware" of the strict, pre-determined limits of disorder beyond which the system cannot go. On the other hand, the engagement of mechanisms that automatically initiate the emergence and development of antichaotic spikes when the system reaches its E_{max} state is the evidence of a system's pre-determined resistance to chaos that is immanent in any system.

Inevitability of the antichaotic reaction of a system in the state of chaos indicates that there is energy that is generated during the system's transition into the state of chaos, which is released in the form of antichaotic thrust. Accumulation of the powerful "energy of chaos" does not contradict the laws of thermodynamics unless we are set to explain all global processes by observing them from a chamber filled with an ideal gas. In the context of this report on results of our study, we will not digress to thorough discussion and substantiation of the idea of potential "energy of chaos" and kinetic energy on the descending slope of the antichaotic spike. Instead, we will refer to one more example based on original and perfectly reproducible results, to demonstrate this phenomenon cannot be explained from the standpoint of any known theories of the fundamental science.

It has been due to the lack of routine quantitative methods for analysis of chaotic situations in complex systems, that the concept of chaos, even in the context of concrete experimental findings or mathematical models, is treated mostly as some sort of an obscure category of philosophical generalizations. In the meantime, as has been established in our experiments by using our unique methods for analysis of chaos in systems of any nature and any degree of complexity, it appears that the world of chaos is extremely diverse and not chaotic at all. Figure 9A shows a detailed view of one of the chaotic spikes registered in the course of the above-referred study of population pyramids of the newly independent states, formerly republics of the USSR. This is one of several spikes corresponding to Armenia. All of them, except for this one, have a "classical shape" as illustrated in Figures 1B, 4A and 4B. The spike shown in Figure 9A has a self-oscillation pattern with 50 waves on the ascending curve and more than 200 waves on the descending slope. This spike, hence all of the 250 waves correspond to the interval of dimension value change by 0.05. The structure of these autowaves is perfectly regular, which demonstrated in Figure 9B showing a close-up view of the last 3% section of the chaotic spikes' descending curve, which is followed by the emergence of a small peak (Figure 1A).

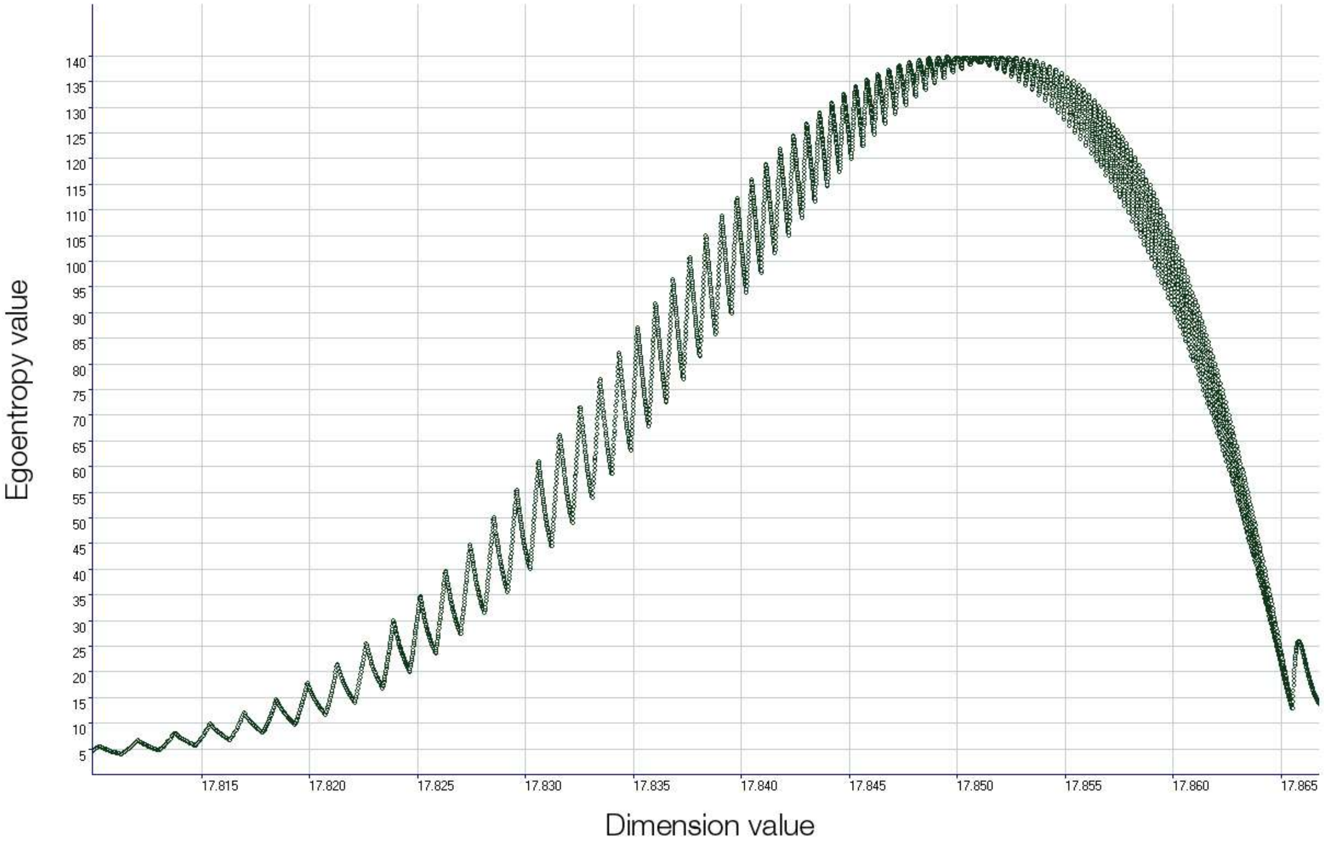


Figure 9A. One of chaotic spikes corresponding to Armenia in the analysis of complexity of the system of data based on population pyramids of the newly independent states, former republics of the USSR.

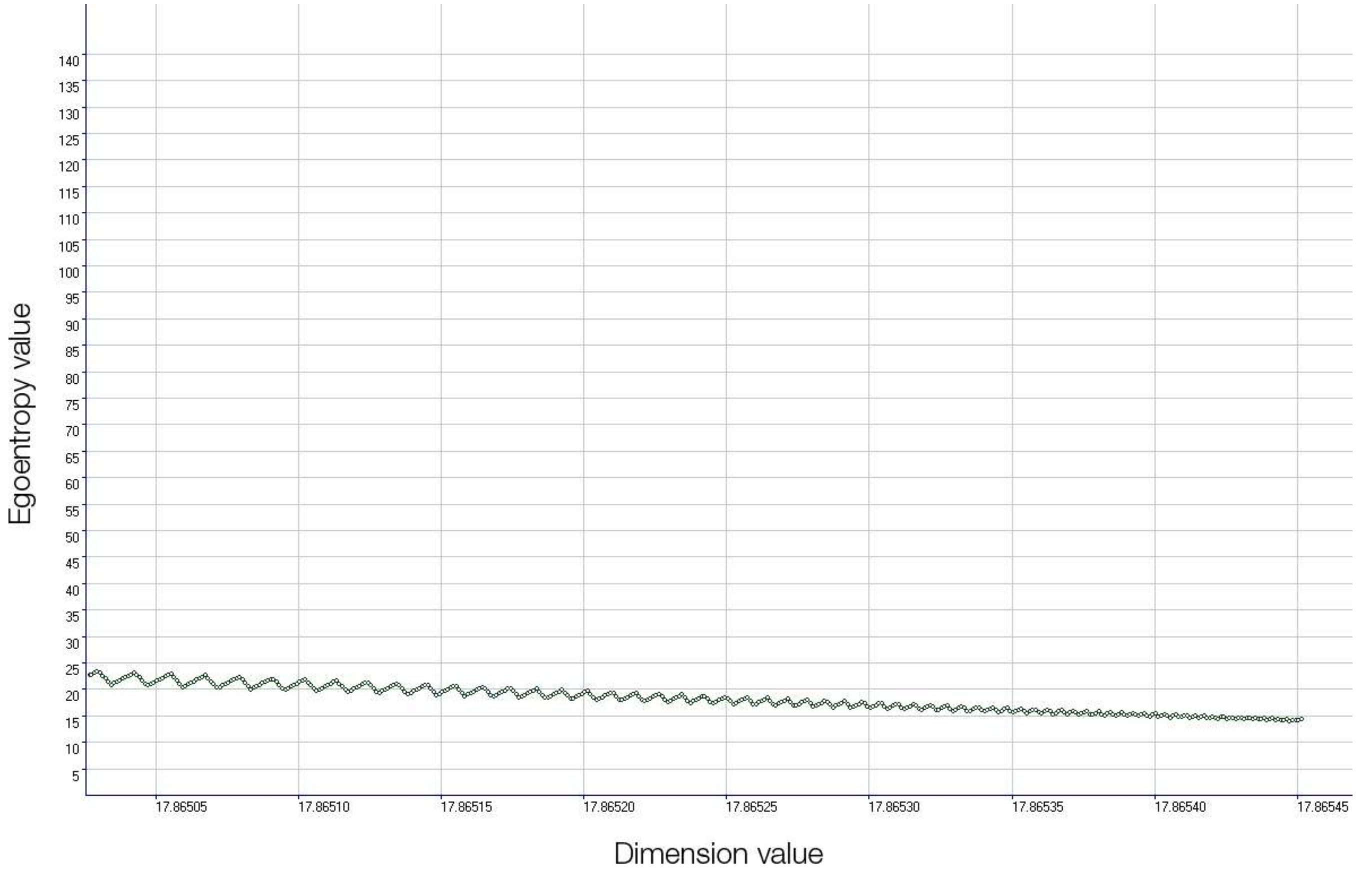


Figure 9B. A close-up view of the last 3% section of the descending curve of the chaotic spike shown in Fig. 9A.

In this context, it is important to point out the following. First of all, chaotic spikes with rudimentary but clearly shaped self-oscillations were also observed by us in very simple 2D systems of scattered points, thus indicating that the phenomenon, illustrated in Figures 5 and 9, is not that exotic. Secondly, autowave chaotic spikes always occur in the environment of non-oscillating spikes. The third important point is that the method we apply in analysis of complexity and chaos does not involve anything that may provoke the emergence of self-oscillating waves on a chaotic spike. Neither the rate of changes in dimension values, nor the frequency of interruptions of dimension value changes have any effect on the shape of a self-oscillating chaotic spike, and all of the recorded chaotic spikes are perfectly reproducible.

In order for an object to oscillate, there must be a force acting on it. The phenomenon of autowaves emerging upon information processing and connected with the changing complexity of a system of data under processing cannot be attributed to any force other than the accumulation of potential "energy of chaos" in a given system and its release in the form of kinetic energy of antichaos. It appears also that the self-oscillating chaotic spike formation is strictly determined by the totality of input data and the character of a parameter that undergoes continuous changes of its dimension. This fact is obvious from the very shape of the spike, especially its descending part. The oscillation period of the last visible waves at the end of the chaotic spike's descending curve is about 1-2 x 10^{-6} of the involved parameter dimension, and the damping of the oscillation amplitude occurs according to a strict pattern. A plot in Figure 10 demonstrates how the amplitude of the ascending curve oscillations depends on egoentropy. The parabolic curve is symmetrical relative to the center of the chaotic spike's ascending curve, which indicates that the chaotic spike's growth is pre-determined. Thus, it is obvious that the origin of the afore-described effects is rooted in a phenomenon whose explanation requires a non-trivial approach.

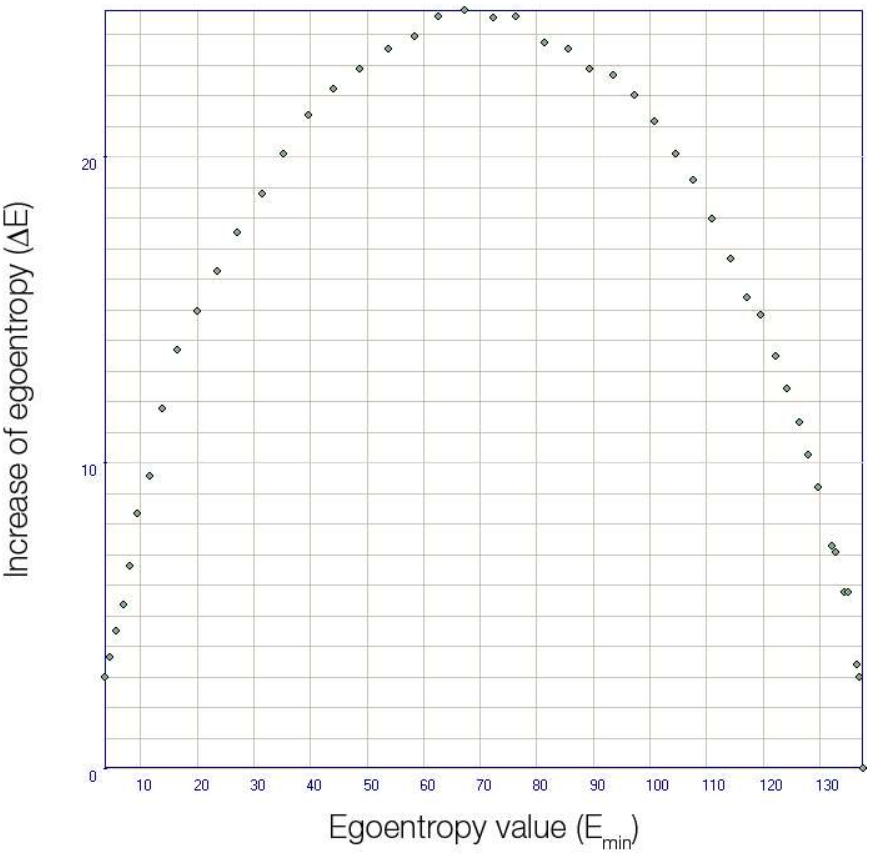


Figure 10. The dependence of oscillation amplitude of the ascending curve of the chaotic spike shown in Fig. 9A, on egoentropy. ΔE is a difference between E_{min} and E_{max} values corresponding to each wave.

As was earlier emphasized, the drastic changes in systems' complexity with the possibility of emergence of generalized chaos were observed occurring at very slight changes in parameter dimensions, in some cases as infinitesimal as by the order of 10^{-7} or less. There is no doubt that the same effects can spontaneously occur in Nature. It is also apparent that the concept of the "energy of chaos", if proven to be more than just a hypothesis, can lead to reassessment of many phenomena for which science has not yet been able to find adequate explanations in the light of the second law of thermodynamics, according to which chaos in closed systems denies the possibility of converting energy into work (perhaps, because the conversion of the potential "energy of chaos" into kinetic energy can be caused only through variations in a system's dimensionality). That being said, this paper is not concerned with either a critique on the second law of thermodynamics or merits of the perpetual motion concept. The effects described in this work stably run in various systems and can be observed by any user of MeaningFinder. In the absence of ready-made scientific explanations for this phenomenon, we can only offer a palliative approach by referring to the "energy of chaos". If this term adequately reflects the essence of the discussed effect, then it can be applied not only to the Universe's processes, but also, to a greater or lesser extent, to any of the global processes. For instance, the centuries-long accumulation of "energy of chaos" in Russia released itself in the early 20th century in the form of kinetic energy of antichaos, which resulted in the establishing of the Communist regime on one-sixth of the territory of the Earth. Russia's antichaotic spike started the ascending phase at about the beginning of the second half of the 20th century and is currently approaching the start of the descending phase of the chaotic spike.

The proposed model of chaos not only corroborates with the Big Bang theory and describes the dynamics of both the Universe's compression and the transition to expansion, but it also provides explanations to the irreversibility of time and the phenomena of pulsars and quasars in which the "energy of chaos" may be mitigated by discrete small portions of antichaos. In the context of the latter, the afore-discussed exception to the general typical pattern of chaotic spike – the "Sacramento effect" illustrated in Figures 5 and 6 – may represent special interest.

The "Sacramento effect" discovered in the above-discussed analysis of a system of climatic data is an exception that confirms the rule – the universal character of the dynamics of energy accumulated in the state of chaos and released as the energy of antichaos. Certain fluctuating processes in the system result in intermittent local antichaotic releases of energy, and after each release the system resumes the accumulation of "energy of chaos". Therefore, the ascending curve of the chaotic spike is so different from the descending phase where local antichaotic spikes do not slow down the accumulation of the "energy of chaos" but, on the contrary, accelerate the natural process of expenditure of the accumulated energy. This explains the different shapes of micro-spikes on the ascending and descending parts of the chaotic spike (Figures 5 and 6). As "energy of chaos" is significantly inhibited by the regularly emerging antichaotic micro-spikes, in the area close to the peak maximum no inverse spike occurs, and this is characteristic of all slowly developing chaotic spikes. When the descending curve of the chaotic spike reaches a certain level close to the zero line and the self-oscillation completely stops, there emerges a small sharp peak manifesting the release of unspent "energy of chaos".

Two kinds of order

The term "antichaos" often occurs in literature and is mostly associated with works by Stuart A. Kauffman who wrote in one of his works: "Chaos, fascinating as it is, is only part of the behavior of complex systems. There is also a counterintuitive phenomenon that might be called antichaos: some very disordered systems spontaneously "crystallize" into a high degree of order. Antichaos, I believe, plays an important part in biological development and evolution" [7].

Strictly speaking, there are two kinds of behavior of complex systems that can be referred to as antichaotic in a broad sense of this notion: 1) prevention of the emergence of chaos, which is performed by trivial mechanisms for regulation without which no life activity is possible at all; and 2) elimination of the emerged chaos. The role of the second type of antichaos in biological evolution is grossly questionable as it consists of two relatively quickly occurring phases of chaos: the utilization of the "energy of chaos" and the recovery of the pre-determined dynamics of chaos. Both processes, although opposite, are derivatives of the general nonlinear of chaos whose emergence is hard to predict and therefore it cannot be used as the evolution vector. All in all, it is hard to fathom how antichaotic processes of this type can stimulate evolution and self-perfection of biological systems.

Apparently, it is more practicable to differentiate between two kinds of the state of order in complex systems – nonchaotic and antichaotic. The first kind of order can be characterized as a state in which a system's complexity is hardly to transform into generalized chaos. The second can be defined as unstable pseudo-order. The technology proposed by us allows the accurate identification of each of these two states.

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