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CHAOS AND MUSIC

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SUMMARY. The Chaos theory describes an unpredictable behavior that occurs in a system that should be governed by deterministic laws. Such systems are highly sensitive to initial conditions, and a very small initial difference makes an enormous change to the future state of the system. Originally, the theory was used to describe the unpredictability in meteorology, but it has been extended to other branches of science. Borrowed from Mathematics, the term "stochastic", which means the calculus of probabilities, has also been applied to the music that contains elements of chaos. Iannis Xenakis used it for musical procedures whereby overall sound contours are determined, but inner details are left to chance or worked out mathematically by the composer or by the computer. Another composer who used the laws of chaos in his music was György Ligeti best known for his thick orchestral clusters.

Keywords: chaos, music, mathematics, Xenakis, Ligeti, stochastic, calculus of probabilities.

Our life is a nonlinear process. It begins with birth and ends with death, dealing with many ups and downs on the way. Often, we think that the constant and firm situations, probably being easy to capture through linear processes, are paradisiacal, but after a short period of the daily routine we usually become bored and seek for a change, that is a nonlinear event. If we think about it for a while, we realize that our life and perceptions are determined especially by nonlinear phenomena, such as events that occur all of a sudden and unexpectedly.

The scientists have tried to explain our world using models based on the linear one. Due to the lack of nonlinear patterns, nobody could classify them and study them further. The last decades' discoveries have facilitated the access to the world of nonlinear phenomena and initiated a unique interdisciplinary research field: the nonlinear science. Unlike the science tending to become more and more branched and specialized due to progress, the nonlinear science brought a lot of different disciplines together. This was motivated not only by the huge importance of a nonlinear science, but also by the extraordinary simplicity of the concepts involved.

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Analogous to an old anarchist slogan, the chaos does not mean the absence of order, but a superior form of it. Recently, the chaos became very popular. The scholars have begun to develop their own understanding of the chaos, by playing with simple algorithms on computers, such as the logistic map. New depths in the foundations of science and nature have been obtained. There are deterministic systems, whose determinism cannot be experimented. The question whether God is playing dies or not suddenly appears in a new light. However, beside these deep philosophical implications, chaos opened a gate toward the making of beautiful fractals on a computer screen. The subjective opinion regarding their beauty can be found in the uncovered harmony, which probably corresponds to the one in the nature. Without overreacting, we may say that the nonlinear dynamics field and the chaos one are walking next to the present *Zeitgeist*, where not only non-conventionality becomes conventionality, but where playing with computers is much more in fashion than playing in nature. The Chaos, as a phenomenon of nonlinear dynamics, is nothing else but a product of our computerized world. So far, almost all the major progresses were based on the work with the computers, although the chaos had been much earlier observed in the experimental systems, without being characterized at that time. Once you become familiarized with it, you can easily find it anywhere in nature.

According to *Encyclopaedia Britannica*, the word chaos derives from the Greek word *χαος*, which meant, in the beginning, the empty infinite space that had existed before all things. The later Roman conception interpreted the chaos as the original, brutal and non-shaped form, in which the Architect of the world brought order and harmony. In the modern use, chaos denotes a state of irregularity and disorder[1].

When thinking about chaos, old people would see it as something creative and immeasurable.

In his *Theogonie*, Hesiod assured his readers: “The first of all things was the Chaos. The next one was the Earth”. The cosmogonies of all cultures imagined a beginning time, when The Chaos or The Nothing were ruling, and the existence and the things appeared unexpectedly. The old Egyptians imagined the Universe at its origins as an abyss without configuration, named Nut. Nut gave birth to Ra, the Sun.

In an old Chinese creation legend, a ray of light, Yang, comes out of the chaos and touches the sky, meanwhile the dark, Yin, left behind, creates the Earth. Yin and Yang, the male and the female, go further to make the ten thousand things (in other words, everything). What draws the attention is the fact that these two principles must keep their balance. Too much of one or the other would bring the chaos back.

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[1] Schuster, Heinz Georg, *Deterministic Chaos: an Introduction*, Tokyo, VCH Verlaggeselschaft, N.Y., Basel, Cambridge, 1995.

In the Babylonian legends, the chaos was called Tiamat, the mother of all things. She and the other old gods personified the Chaos's different faces. For instance, there were a god who symbolized the boundless distances of the abyss and a god who represented the Untouchable and the Impenetrable, both watching in the disquiet. The Babylonian belief, that this lack of form could yet have different faces, in other words a kind of implicit order, had to wait for thousands of years in order to be rediscovered by the modern science.

The mythical idea, according to which the strange power of creation is based on the mutual relationship between the order and the disorder, survived all the way to the monotheist cosmogonies, as it is the one of the Christianity. The biblical universe was empty and wild, with no form, until God created and ordered it. The Flood, the Devil and Jesus' agony – the chaos becomes obvious. When Jesus was being crucified, as "the earth did quake, and the rocks rent and the graves were opened", the disorder was threatening to take creation's place.

In order to be a Creator, God needed to work within unclear boundaries between the Order and the Chaos. Many cultures shared this type of vision. The personality that comes out of the fog of this field of limits is Dionysus, the god of the obsession that can be found in every culture of the world; it is the Indian god Shiva, the one who lives in dreadful and horrifying places[2].

Where the chaos begins, the classical science ends. As long as the world had physicists that studied the laws of nature, the disorder in the atmosphere, the turbulent sea, the fluctuation of the populations living in the wildness, or the oscillations of the brains and heart were being ignored. The irregular part of the nature, the discontinuous and the strange one – these were mysteries for the scientists, or even worse, they were the monstrosities.

During the '70s, a few scholars in the USA and Europe began to find a way through disorder. They were mathematicians, physicists, biologists and chemists, all searching for connections among the various kinds of irregularities. The physicists found a surprising order in the chaos that develops in the human heart, the first cause of sudden, incomprehensible death. The Ecologists explored the increasing and decreasing of the moths' populations. The Economists eliminated the old data referring to the prices and they tried a new type of analysis. What came out led directly to the natural world – the forms of clouds, the traces of lightning, and the microscopically knit of blood vessels or the galactic clusters of the stars.

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[2] Briggs, John - Peat, David F., *Die Entdeckung des Chaos*, Deutscher Taschenbuch Verlag, München, 1989, p. 23.

Now that science researches that, the chaos seems to exist everywhere. It shows up in the behavior of the weather, in that of a flying plane or of the oil in the pumps. Regardless of the environment, the behavior subdues to the same discovered laws.

The Chaos dissolves the limits separating the scientific disciplines. Being a science of systems' global nature, it brought together thinkers from fields once widely detached. The science of the chaos breaks along the traditional scientific disciplines, bringing together unconnected types of wildness and irregularity: from the turbulences of weather to the complicated rhythms of the human heart, from the shape of the snowflakes to the winding sands in the desert. Mathematical in its origins, the chaos is a science of the everyday world, formulating questions that every child asks: how do the clouds form, how does the smoke lift up, how does the water flow.

The daily experience shows that, for a lot of physical systems, small changes in the initial conditions lead to small changes in the result. For instance, if we drive and change the direction of the wheel just a little, our trajectory will differ insignificantly from the one the car would have taken without making this change. But there are cases when the contrary is valid: for a coin put on its edge, a slight touch is enough to determine the part on which the coin is going to fall. Thus, extremely small changes in the original state can lead to totally different outcomes.

It has become very clear in the past few years that, in part due to the study of the nonlinear systems, a sensitive addiction to the primary circumstances – which results in a temporal chaotic behavior – is far from being exceptional, being in fact a typical feature of many systems. Such a behavior was found, for instance, in periodically stimulated cardiac cells, in electronic circuits, in the turbulence attack in the fluids and gases, in the chemical reactions, the lasers and so on. Mathematically, all the dynamic nonlinear systems with more than two grades of liberty can manifest chaos, becoming unpredictable on the large temporal scales.

The deterministic chaos is now a very active research field. Methods to classify the types of chaos have been developed and it has been discovered that a lot of systems show transitions from order to chaos.

The nonlinear dynamics claims to be the oldest among the scientific problems. Among its few rivals in longevity we find the geometry. The scientist who discovered the dynamic geometry is generally recognized to be Henri Poincaré (1854-1912).

The Chaos is a non-periodic movement. When two identical systems are being started in almost equal conditions, the two movements deviate from one another at an exponential ratio. Naturally, if the original conditions were the same, the deterministic nature of the equations would guaranty the matching movements all the way. But certain insecurity in the original position is inevitable in all the real physical systems, and the divergence of the identical movements in the chaotic structure cannot be avoided.

The Chaos is a dynamic, temporal characteristic of a nonlinear system, being set through the so-called *strange attractor*.

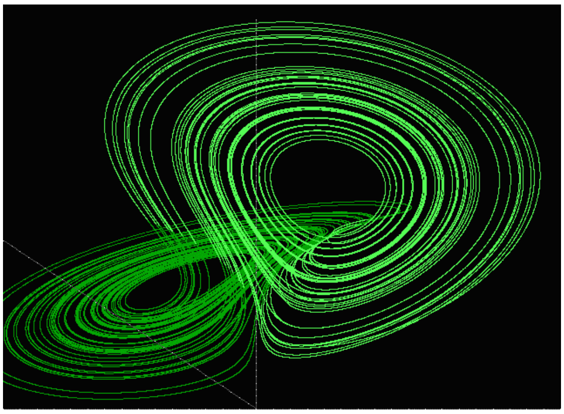


Fig. 1 Strange attractors

Its geometric structure is called *fractal*, term established in 1967 by Benoît B. Mandelbrot.

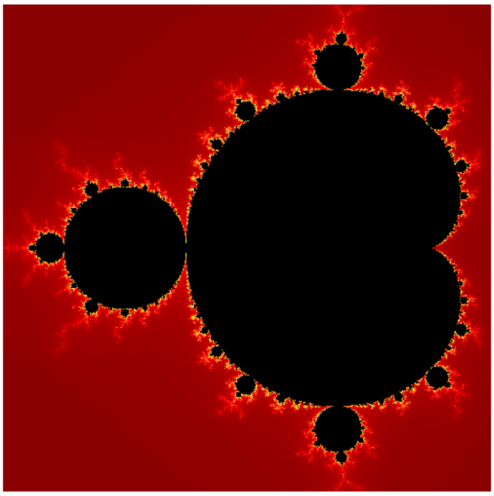


Fig. 2 Fractals

The Fractals are being underlined through the fact that their geometric configuration differs from the known dimensionality of the Euclidian space (which can be characterized through whole positive numbers) and their physical dimension varies from the one of Newton's mechanics, lying somewhere in between those two. These dimensions are described through "broken" numbers. The word "fractal" derives from the Latin word *fractus*, meaning to brake, split, smash. The modern technique stimulates the researches regarding the applications of the fractals in science, technique, art and so on.

An important cause for the emergence of fractal geometry was the observation that the objects from nature own a resembling structure, i.e. they look alike or almost alike, and they depend on the way one looks at them (the so-called phenomena of scale invariance). This applies, for instance, to the lines of the seashore, as well as for the ramifications of the trees. In the fractal geometry, the observed phenomena are being described through mathematical patterns, where a simple principle of construction is constantly continued on smaller sizes, having as a result the fractals of their selves.

Plato insisted on the principal of causality, "for it's impossible for any thing to exist without a cause" (*Timaeus*). Strict causality lasted until the 19th century, when it suffered a brutal and productive transformation, as the result of the statistic theories in physics. Going all the way back to the Antiquity, the concepts of "happening" (*tyche*), "disorder" (*ataxia*) and "disorganization" (*asystasis*) were considered as the opposite and the negation of "the reason" (*logos*), "the order" (*taxia*) and of "the organization" (*systasis*). Only recently, the knowledge was able to penetrate the hazard and discovered how to separate its levels[3].

The stochastic music can be defined as somehow "arbitrary" music or as the music that contains some elements of hazard. Xenakis's works will almost always be mentioned in connection to this. In mathematics, stochastic is nothing but the calculus of probabilities.

In 1975, Richard Voss and John Clark brought a contribution to the principle of hazard in music. Both researchers measured physically the hazard that was present in the music and speech and discovered a "noise" with a spectral density of 1/f, which can be found in the total chaos between the so-called "white noise" and "brown noise". Through noise, we understand a mathematical operation, which tries to analyze the occurrence of the chaos – such as the radioactive disintegration – and to produce "art" (we refer to "noise" as an abstract notion, not an acoustic one)[4].

Voss and Clark linked this noise to the musical stochastic composition and generated electronically, through digital signals, different types of analogue noises.

[3] Xenakis, Iannis, *Formalized Music*, Pendragon Press, Hillsdale, NY, 1992, p. 4.
[4] ***, *Die Musik in Geschichte und Gegenwart*, Ed. Bärenreiter, Kassel, Basel, London, New York, Prag, Metzler, Stuttgart, Weimar, 1997, vol. VI, p. 793.

Martin Gardener showed in 1978 how chaos generators could build music. By throwing a die, the white noise is stimulated (a sound is being chosen arbitrarily), and by throwing the die twice successively, the brown one (named after the Scottish botanist Robert Brown) is stimulated. If we have, for instance, an even number, the sound stands a tone above the precedent one, and if we have an odd number, the sound stands a tone below it.

Connections between music and mathematics appeared also by relating to the scientific knowledge of chaos research, of its theories (on one hand in the field of the fractal geometry and, on the other, in the field of the complex dynamic systems).

With the help of the computers, the calculated fractals can be imagined in two-dimensional pictures. These images have been first taken over in paintings and then in musical composition, especially in the one made on the computer. Analogous to the “spatial” fractals from geometry, the specialists have tried to obtain the “temporal” ones in music. Charles M. Dodge presented in the work *Profile* (1988) a structure based on the concept of fractal and similar to Koch’s so-called “snowflakes” (starting from an equilateral triangle with the side length a, another triangle with the side length a/3 is being overlapped, so that when this principle is continually applied, a constantly curve appears, that is similar to the snowflakes).

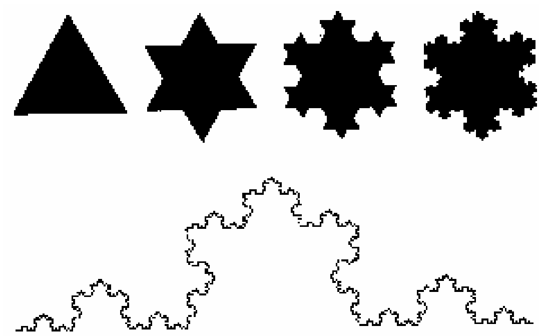


Fig. 3 Koch’s snowflakes

The fractal attribute lies in the form and the structure of the composition: the musical motives have a three-voice technique, in various durations. The initial point and the sound material of the first voice are built from the basic motive, generated chaotically from many sounds. Each sound of this first voice has an adequate following motive, similarly generated, and all the motives together make the second voice. The same goes for the third voice.

The idea about the resemblance among the objects found in nature led to attempts in musical theory and to analysis to demonstrate music's fractal quality. Thus, J. Kenneth and Andrew Hsü tried (1990/1991) to show the fractal dimension of two of Bach's two-part inventions.

Another important branch of the chaos theory deals with the reflection upon dynamic systems, which have as a starting point the discovery that complex systems (such as weather or population expansion) would admit certain predictions about the future development, but would be completely unpredictable in detail. On one hand, these systems show a certain capacity for self-regulation, so the interior and exterior confusions can be caught and calmed, and on the other, a tiny impulse can be amplified. As an example, we have the butterfly effect: the wings beatings, at proper dimensions, can start a storm. David Little created a musical pattern of this effect in his composition *Shuffle*. Other composers who worked with mathematical patterns are Bruno Degazio (1986), Jeff Pressing (1988, 1992, 1993) and Michael Gogins (1991).

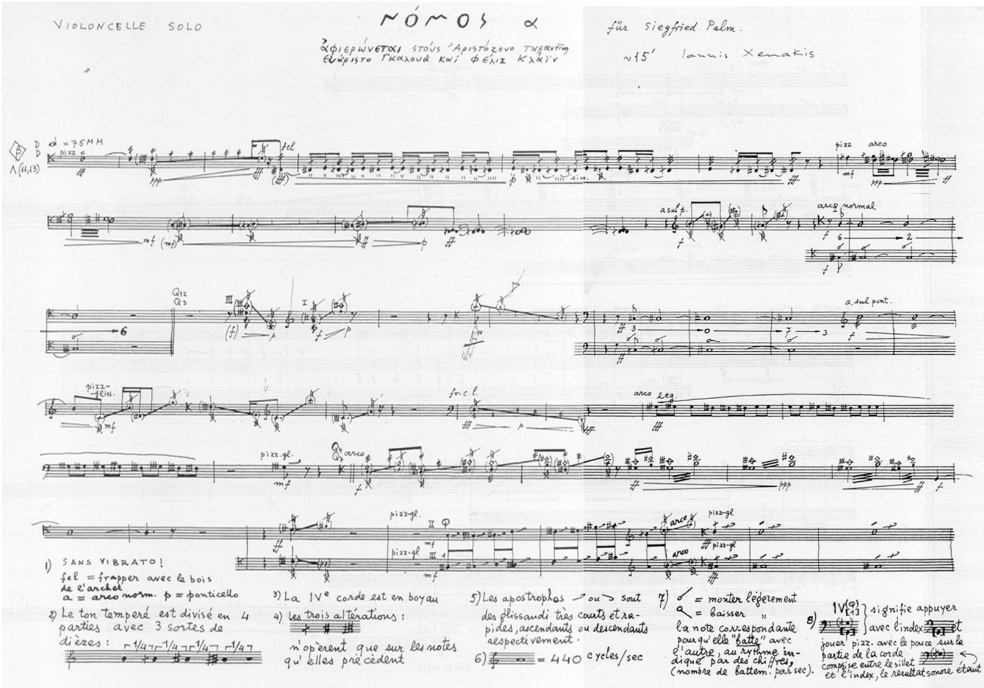
Because Xenakis's compositions were much requested, he used to compare them with Maxwell-Boltzmann's law of distribution. This law deals with the description of the molecules. The establishment of "before" and "after" (the last step in the compositional process at Xenakis) is entirely independent of the ways of illustrating the structures outside the time. However, the questions about periodicity and non-periodicity play an important role for the temporality of the music too. The dynamic developments are capable to reveal the huge field between order and chaos – just like in the case of the stochastic method. In *Nomos alpha* and *Nomos gamma*, each transformation describes a change in position of the musical vectors. The temporal succession of musical situations can be explained, so that every situation can be given an index, which indicates the position taken in the successions. In these two compositions, structures outside time are being portrayed and geometrical symmetries are being researched through their invariance toward certain groups of transformations.

The chaos from a dynamic system has nothing to do with the hazard. In order to make the difference, they talk about the "deterministic chaos". Each situation of the dynamic system is clearly fixed by a certain law. The Chaos in the dynamic systems does not mean indeterminism, but only incalculability. Xenakis talks about the "non-deterministic" movement: "There is no deterministic movement. Today, we have knowledge, due to Poincaré's work, of the so-called 'strange attractors'. They exist in physics, astrophysics, and also in music"[5].

[5] Hoffmann, Peter, *Amalgam und Kunst und Wissenschaft. Naturwissenschaftliches Denken im Werk von Iannis Xenakis*, Peter Lang, Frankfurt am Main, 1994, p. 137.

Ex. 1

Nomos alpha



One of the main works from the ‘80s is, without a doubt, *Horos* for orchestra (1986). In this work, similar to the models from the hydrodynamics, Xenakis configures the so-called partial sound stream.

> “For instance, in measures 99 and 100, the musical patterns appear one after the other, in phases. At the beginning, we have the winds playing, then the chords playing more or less the same motive, but not beginning from the same point. Nevertheless, the time unit remains the same. This generates turbulences in flux, currents that go up or down or return to the same spot. It must be exactly like [in] a fluid”[6].

Another important composer who uses the principle of chaos in his music is György Ligeti, who is permanently searching for new possibilities of expression, new elements for a continuous development of the musical language. His interdisciplinary interests are well known – literature, plastic arts, physics, mathematics, biology, electro acoustics and the chaos research (fractal geometry).

[6] *Ibid.*, p. 145.

Having the chance to work at the Studio for Electronic Music in Köln, WDR, in 1957-1958, Ligeti came closer to the analytical path of a music, whose access had been denied permanently in Hungary. Thus, he will develop a new style, where serial music plays an extremely important part, formulating little by little his own ideas, from concepts like "time" and "space". These concepts will mean a lot for his future work: the chronometrical time is transformed into an imaginary space. The creation of form is being done from musical levels as a texture, to complex musical knits, noise structure and changes of the color of the sound.

Apparitions was the first composition in the new style and Ligeti succeeded, with the work's premiere on the nineteenth of June 1960 in Köln, the great step as a composer. In this work and in the ones that followed, Ligeti self-imposed his typical and famous principle of "micropoliphony", of "imperceptible" polyphony, distinct through its overlapped sound textures. The isolated changes of the voices can not be heard consciously: their perception remains an inferior one. What the ear perceives is nothing but an oscillating sound structure.

Ligeti's main innovation in this work was the orchestral cluster: the static strip of a sound, where the volume and instrumentation remain the same for a long period of time and where the sense of harmony is destroyed.

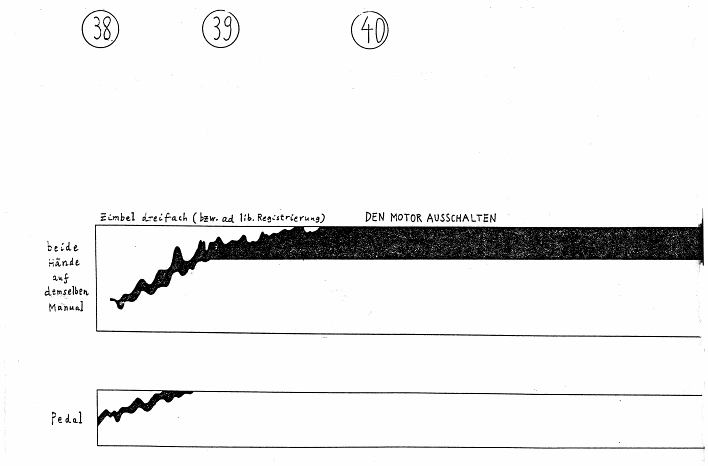
A subsequent development of the principles of the texture and the cluster followed in 1961, when the work for the orchestra *Atmosphères* appeared. Its premiere, during the Festival in Darmstadt, had all the signs of sensational, as no one had tried to fulfill such a level of deconstruction until then. What can be heard are the changes in the sonority and texture as well as the permanent alterations in the color of the sound; the sound moves towards super parameters. The traditional images, the profiles of the sounds and the rhythmic contours disappear entirely; a static music, without measure or periodic impulse emerges.

The work for organ *Volumina* (1961-1962), based exclusively on clusters, can be seen as a partly transcription of *Atmosphères*: there is, again, only one break, when the extreme bass interrupts the extreme acute. Both pieces finish with a gradual fading, achieved in *Atmosphères* by letting the chords to vibrate and in *Volumina* by turning off the instrument's engine, while both hands maintain a cluster. In the latter work, six types of cluster are graphically described: the chromatic clusters, the diatonic clusters, the pentatonic clusters, the clusters with instable shapes and the clusters with internal movement[7]. Typical for both works is the almost absolute lack of caesuras. The formal aspect of this music is the static, inside which the changes are however present.

[7] Burde, Wolfgang, *György Ligeti. Eine Monographie*, Atlantis Musikbuch – Verlag AG, Zürich, 1993, p. 131.

Ex. 2

Volumina



In the first from the *Klavier Études*, called *Désordre* (in some way programmatic in the meaning of an order – chaos deviation), the original material is unusually simple: the twelve sound of the total chromatic are divided between the two hands, building a heptatonic mode on the white keys at the right hand, and a pentatonic one on the black keys at the left hand. Under these clearly stated conditions, the study is sent away on two paths, because beside the different long melodic cycles (r.h. 4+4+6=14 measures / l.h. 4+4+8=18 measures), Ligeti brings a second irregularity: at the right hand, every fourth measure is being shortened with a quaver, so that the two levels move increasingly one toward the other. The “disorder” announced from the title is amplified exactly because of this type of small disturbing elements.

In Ligeti’s narrow textures, made out of joined semitones, the components like rhythm, melody, harmony or intervals’ contours cannot be perceived. The composer explains the existence of the compositional process as the “change of a raw state into the knit of a net”. Through their different clothes and their equivocal transformations relationships, Ligeti’s forms and genres are permanently modified. By passing all the time from chaos to order and vice versa, the energy that the form needs is accumulating:

> “These are very simple elements, but through multiplication, through the slightest change of place, overlapped patterns, hyper patterns appear, patterns that could be seen as hyper signals. That’s precisely how it happens in fractal geometry” (Ligeti)[8].

[8] Kostakeva, Maria*, Die Imaginäre Gattung. Über das musiktheatralische Werk G. Ligetis*, Peter Lang GmbH, Frankfurt am Main, 1996, p. 67.

Thus describes the author the idea of chaos and order in *Désordre*.

Ex. 3

Désordre

Ligeti elucidates the concept from *San Francisco Polyphony* as a game of changes between order and chaos: the melodic lines and patterns taken separately are closed and ordered in their selves. Their combination, both simultaneous and successive, is chaotic. In the big form, in the lapse of musical events, order can be found again – "we can imagine separate objects, which are thrown into a drawer, in a huge disorder, but the drawer has nevertheless a definite form again: the chaos rules inside, but the chaos itself is very well configured"[9].

The work is therefore a complex construction, conceived as a fluent form, typical for the nature as well. This is the way music becomes a projection of nature, but also an experimental science. Ligeti's models of musical form, which set the ground for the changing from order to chaos and back, are found all over the nature. This explains the composer's attention for the field of synergy, as well as for that of the turbulences in the laser rays, the meteorology, the clouds, the economy, and the population. What brings Ligeti's music in connection to the natural processes and fractals is the fact that all these exist as highly ordered hyper systems.

The change effects produced by a chaotic system are the foundation of the theory of chaos. Due to this theory, we get a new outlook, that of the immeasurable, of the unpredictable in the world, in the art. Ligeti draws the attention specifically on such musical deeds. He refers to the two sources, which are extremely important for the developing of the contemporary music (especially the one made by Boulez and Stockhausen): Webern's constructivism and Debussy's "sound chemistry".

Next to these two sources, the composer talks about the heterogeneous levels and the role of the polyrhythmic model in the non-European cultures, patterns that can be found in his music, especially in the works composed at the beginning of the 80's. They define a type of structural thinking. The effects when changing the meter in the African music fascinate Ligeti. When he calls the building of a complex structure from polyrhythmic levels a "frozen turbulence", he does not do this because of finding a new poetical metaphor, but in order to express something new from the structural viewpoint, for which no suitable term exists yet. Thus, the metaphor remains the only way to structurally describe the idea of a work: "a current similar to itself emerges, one of the ideas of the composition brought about by the already mentioned *fractals*" (Ligeti)[10].

The same thing can be found to best describe things like: "the whirlwind", "the cyclone" and "the anti-cyclone", "the magnetic fields", "the detonations" and many others. Using a metaphor, Ligeti tries to illustrate a certain musical organization, a technique of composition, a factor that builds the form and even the musical material.

The notion of *chaos* names a new quality of the uncertainty in describing the world. Its research seems to point toward a science that, on one hand, must resign itself to the considerable restraint in evaluating the world, but on the other gives access to the unsuspected richness of the forms and its ensembles.

(Translated into English by Oana Andreica)

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[9] *Ibid.*, p. 69.
[10] *Ibid.*, p. 70

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