Iannis Xenakis and systems thinking

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This paper focuses on the link between the musical thought of Iannis Xenakis and theories of *systems thinking*. It will be demonstrated how the composer interprets in his musical thought, concepts of systems thinking, such as *markovian stochastic music*, or in the formulation of *second order sonorities,* which resulted in the formation of a new music paradigm. Finally, we shall examine how these lines of thought evolved, as for instance in the music of Agostino Di Scipio or in my own music.

One of the most acknowledged characteristics of Iannis Xenakis' music is his application of mathematical ideas in musical composition. What may not be as widely discussed though is the significance of *systems thinking* in Xenakis' approach. Following a general introduction of systems thinking, we shall move to Xenakis' famous critique on serialism, where he introduced the notion of probability in music composition. Due to this critique and because of Xenakis' general attitude to the application of mathematical formalisation in composition, his work is associated with mathematical thinking. Nevertheless, equally important in the whole of Xenakis' œuvre is the influence of systems thinking – I have previously shown some aspects of systems thinking's impact on Xenakis' music (Kollias 2007; 2008; 2009b) that will be further developed here.

Here, we shall first discuss the connection of Xenakis' *markovian stochastic music* with Ashby's *cybernetics* in detail, and then move on to consider Xenakis' hypothesis of second order sonorities in relation to another aspect of systems thinking. Finally, the importance of systems thinking as a tool in the establishment of an epistemological perspective of music is pointed out in the context of my work and that of Di Scipio's.

What is systems thinking?

Systems thinking "can be viewed as a metalanguage of concepts and models for transdisciplinarian use", as Charles François puts it (François 1999, 203). Systems thinking have learned over the years from several aspects of human knowledge and have in turn influenced numerous aspects of today's thought and practice, not excluding the arts and music. Direct applications of these theories are useful devices like computers or robots, or lethal applications like 'clever bombs'. Systemic concepts have been applied to fields like psychology, sociology, the physical sciences, economics, politics and almost every other aspect of today's organised thought.

The main framework of systems thinking is the treatment of organised entities. In this viewpoint, everything can be considered as a system that can be modelled. Goals can be defined, and general properties can be observed. Diverse phenomena can show similar systemic properties - such phenomena can be described by notions like feedback, interaction, self-organisation, emergence, enaction etc. Patterns of bird flocks, consumer's tendencies in the global market, or the interactions of species within an ecosystem can be equally modelled as *complex adaptive systems,* using the same set of conceptual tools. I have previously introduced several systemic concepts and discussed their applications in music (Kollias 2007; 2009a).

Depending on the context in which systems thinking is applied, one may come across different terms, like: systems theory, systems approach, systems science, systemics, cybernetics, cognitive studies, complexity theory and others. For instance, on systems thinking, the focus may be on the effective modelling of reality, whereas a cognitive approach may be concerned with an epistemological perspective. Nevertheless, modelling cannot be done without a cognitive viewpoint, while the search of what and how we know something cannot ignore the fact that there is always an observer attached to the model of the reality he creates. Both approaches are two sides of the same coin.

Xenakis and Systems Thinking

Starting with his polemic reasoning against the supremacy of serial music, Xenakis claims that "the quantitative and geometric part of all music, becomes predominant with the Viennese School" (Xenakis 1994, 39).[1] In this way, with a delicate rhetoric move, Xenakis transfers the 'battle' in the domain of his expertise, the domain of logic and mathematics. He further argues that there is a contradiction between the linear polyphonic system and its sound result. Therefore, what is really important is "the statistic average of isolated states of the components' transformation in a given instance" (Xenakis 1994, 42).[2] As a solution, Xenakis suggests the introduction of the notion of probability into music composition.

With the introduction of these mathematical ideas into music, Xenakis manages first, to explain the general tension in the music technique of his era and then, to suggest the necessity of the next step, that of the probabilistic notion. Mathematical thinking in music composition refers to the abstraction of sound elements, their quantification and the formalisation of their relationships. That is to say, it is the rationalisation of sound's control. Although the use of mathematics as a compositional tool does not necessarily suggest aesthetical values or particular modes of perception, the application of stochastics through a cybernetic epistemology opens a new field of music creation and experience.

It seems that in the beginning, the connection of Xenakis' music with cybernetics was intuitive. In his critique of serialism mentioned above, first published in 1955, along with the probabilistic concept, he is introducing the concept of *transformation* (see above, Xenakis' second quotation). Notably, transformation is the key concept of cybernetics. We know that by 1957 he is aware of cybernetics and he is already studying it. In a letter to Hermann Scherchen, in 1957, Xenakis writes:

> I found that the *transformations* which are on the basis of cybernetics, I have already thought and used them in *Metastaseis* without knowing that I was doing cybernetics! (quoted in Solomos 2008).[3]

It is also noteworthy to mention that in the description of Xenakis' *markovian stochastic music*, the composer is using the method of Ashby found in *An Introduction to Cybernetics*, applying it to music more or less step-by-step. In his works *Duel* (1958-59) and *Stratégie* (1962) Xenakis is using ideas of *game theory*, another aspect of systems thinking, while describing the basic ideas through common cybernetic notions. More particularly, he explains that the musician and the conductor have the role of the output's control, through feedback, which they compare with the input's signal. He compares this model with a servomechanism. Later he is also applying the theory of cellular automata in his music, like in his works *Horos* (1986) and *Ata* (1987).

Why would Xenakis be interested in systems thinking?

Cybernetics can be considered as the first in depth manifestation of systems theory to be established in the end of 40's. As Francisco Valera suggests, one of the basic aims of cybernetics was the attempt to organise a *science of the mind* (Varela 1996, 29-30). From this perspective, what was previously monopolised by philosophers and psychologists became the subject of study of interdisciplinary teams. In this way, they would search to find the underling processes of the mind, to describe them by explicit mechanisms and mathematical formalisations.

This line of thought may help explain the reason for Xenakis's interest in systems thinking. As described by Solomos, in the Xenakian aesthetics, with a clearly anti-romantic attitude, the focus is no more in the human 'heart' but on the 'brain'; no more on sentiment but on emotion (Solomos 2008). For Xenakis *logic* is now the queen of the arts, no more it is *beauty* (Xenakis 1992, 4).

Another reason is that for Xenakis the art was not a matter of cultivated minds, an attitude that was leading away from the biological foundations of human; an attitude that would result into a 'sterile desert', as he puts it (Xenakis 1992, 43). Instead, Xenakis is stretching out the *sensorial aspect* of music, to directly connect the human biological nature with human intelligence (Xenakis 1992, 42).

A third reason is Xenakis' tendency towards *universality*. Xenakis envisages a new kind of musician, one that possesses "a sort of universality, but one based upon, guided by and oriented toward forms and architectures" (quoted in Keller and Ferneyhough 2004, 163); a musician that knows mathematics, logic, physics, chemistry, biology, genetics, paleontology, human sciences and history.

Wiener, one of the founders of cybernetics, explains the situation in the scientific community during the end of 40's:

> There are fields of scientific work, […] which have been explored from the different sides in which every single notion receives a separate name from each [scientific] group and in which important work has been triplicated or quadruplicated while still other important work is delayed […] that may have already become classical in the next field (Wiener 1965, 2).

And Wiener continues:

> For many years Dr. Rosenblueth and I had shared the conviction that the most fruitful areas for the growth of the sciences were those which had been neglected as a no-man's land between the various established fields (Wiener 1965, 2).

Similarly, Bertalanffy's *Society for General Systems Research* declares among its first objectives, the investigation of a common language of concepts, laws, models in the different scientific domains and the promotion of the unification of science (von Bertalanffy 2006, 15).

To make the connection with Xenakis, an interdisciplinary theory formed by different branches of sciences and with a main objective to find a universal scientific language, would strongly fascinate the composer.

Another important aspect of systemic thought, also connected with universality, is the concept of *isomorphism.* According to von Bertalanffy:

> The consequence of the existence of general system properties is the appearance of structural similarities or isomorphisms in different fields. There are correspondences in the principles that govern the behavior of entities that are intrinsically, widely different (von Bertalanffy 2006, 33).

Similarly, Xenakis states:

> any theory or solution given to one level can be assigned to the solution of problems on another level. […] [Q]uestions having to do mainly with orchestral sounds […] find a rich and immediate application as soon as they are transferred to the Microsound level […]. All music is thus automatically homogenized and unified (Xenakis 1992, vii).

Xenakis's markovian stochastic music and Ashby's cybernetics

There are numerous things to say about the inspiration of Xenakis by systems thinking. Thus, I will limit myself to the introduction of some aspects regarding the connection of Xenakis' Stochastic Music and Ashby's cybernetics. In this way we will come closer to systemic theories in order to understand better the visions of Xenakis and we may also start identifying implications not yet articulated.

Starting with cybernetics, as introduced by Ashby, in the basis of cybernetics there is the concept of *difference:*

1. the difference between two discernable things
2. the difference between a thing changing to another (Ashby 1999, 9)

To model something means to abstract it from reality, to create a map explaining the part of the reality that we are interested in. Nevertheless, the map is not the territory; the model should never be confused with the reality. That is because the basis of the modelling concept is to reduce information to just the essential. Consequently, we start by describing only *perceptually significant change*. And this change we describe only in *finite steps*, whereas nature is a never-ending continuous flow of changes.

Let us now take the concept of *transformation*. Ashby is using the example of change occurring from the exposure to sunshine (Ashby 1999, 10) (Fig.1). Consider a pale skin that changes into dark skin. Change occurs on the colour of the skin, where pale skin is the *operand* and dark skin is the *transform*. Sunshine is the factor that causes change and it is called the *operator*. This whole process of change is a simple *transition* (transition I in the example of fig.1). Nevertheless, the concept of change in reality is more complex than just a simple transition. In the example of exposure to sunshine, there are also many other observable transitions that take place, like cold soil becoming warm soil (transition II), the unexposed photographic plate becoming exposed photographic plate (transition III) etc. Finally, a *transformation* is a set of transitions caused by the same operator.

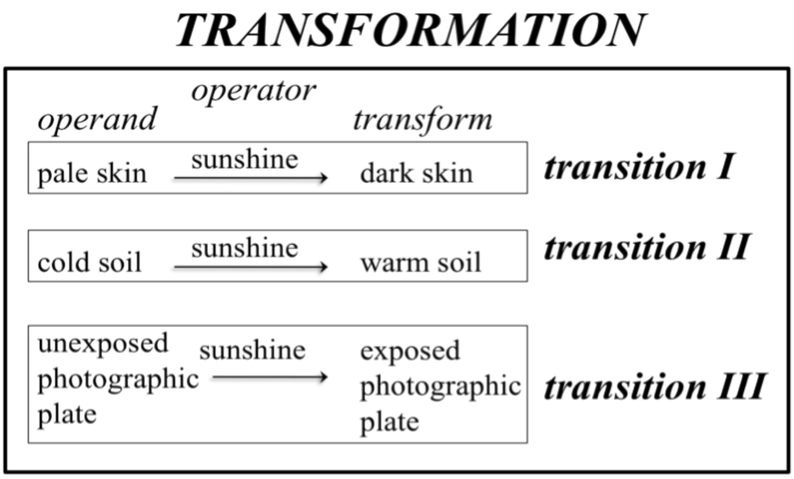

Figure 1. Ashby's example of transformation.

It is important to keep in mind that the "transformation is concerned with *what* happens, not with *why* it happens" (Ashby 1999, 11). Also, in the most cases it is not important to know the operator but it is essential to know the way it acts on the operands.

Xenakis describes what he calls markovian stochastic music starting with a basic hypothesis: "All sound is an integration of grains, of elementary sonic particles, of sonic quanta. Each of these elementary grains has a threefold nature: duration, frequency, and intensity" (Xenakis 1992, 43). Xenakis explains his hypothesis with a metaphor, where "a complex sound can be imagined as a multicolored firework in which each point of light appears and instantaneously disappears against a black sky" (Xenakis 1992, 43-44). From a cybernetic perspective of Xenakis' hypothesis, in order to model any complex sound, duration, frequency and intensity are the only three parameters interest us. So we have F for frequency, G for intensity and T for duration.

In order to describe the sound in finite steps, Xenakis takes chunks of time of *unchanging* length in order to simplify the model and keep only two changing parameters. This way, in every instance, the *state* of a grain can be described by a vector (*f*, *g*) where the *mapping* (the correspondence) between the frequencies and the intensities can be *single-valued* or *many-valued*. That is to say, in the former case a frequency can correspond only to one intensity while in the latter case, a frequency can correspond to many *possible* intensities. Xenakis show this correspondence using again Ashby's methodology. The representation can be extensive (term by term – standard representation in Ashby's terminology – fig.2), a matrix (in the form of a table – fig.3) or canonical (in the form of a function – fig.4):

Frequencies		f_1	f_2	f_3	f_4
Intensities	$\downarrow$	g_3	g_n	g_3	g_h

Figure 2. Extensive representation of grains (Xenakis 1992, 44).

↓	f_1	f_2	f_3	f_4	f_5	f_6	f_7	$\cdots$
g_1	+	0	+	0	0	0	+	
g_2	0	+	0	0	0	+	0	
g_3	0	0	0	+	+	0	0	
$\vdots$								

Figure 3. Matrix representation of grains (Xenakis 1992, 44).

$$\sqrt{f} = Kg$$
$$f = \text{frequency}$$
$$g = \text{intensity}$$
$$K = \text{coefficient.}$$

Figure 4. Canonical representation of grains (Xenakis 1992, 44).

It has to be noted that Xenakis uses here Ashby's method of standard representation and representation by matrix in order to map frequencies with their corresponding intensities. Instead, Ashby originally is using these methods to represent a transition of a state to another.[4]

A transition of a grain's state s_1 to another state s_2 is represented each time by a vector (f_1, g_1) – the operand – changing into (f_2, g_2) – the transform. But if a complex sound is the constitution of myriads of grains, then for the transformation of a sound we need in each chunk of time to describe all grains' transitions.

Xenakis explains this transformation with the use of screens (fig. 5), where in each chunk of time each screen represents the parallel transition of grains. The representation of a sound in time needs countless screens exposed with a constant rate, in a similar way as in a film the static images are exposed with a constant speed on the big screen to create the sense of moving images.

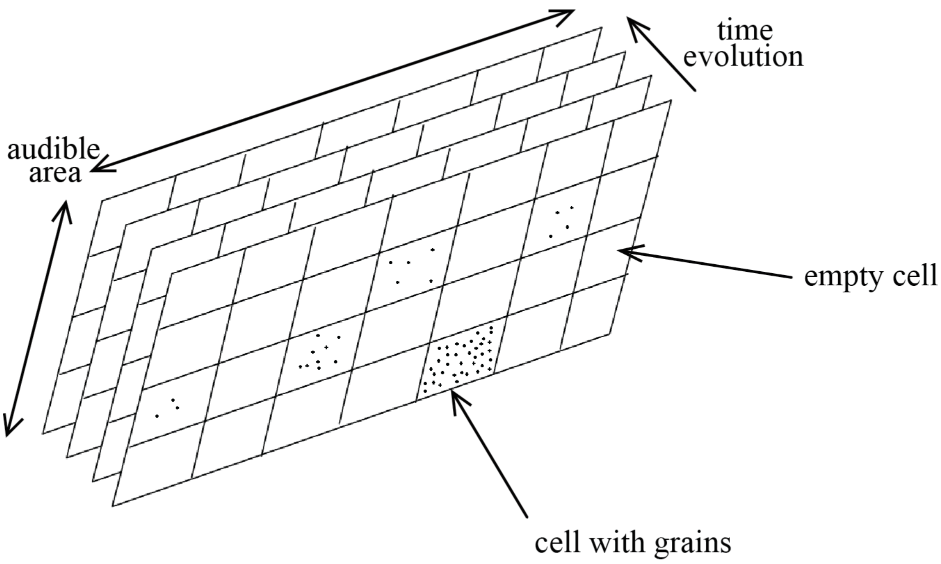

Figure 5. Representation of Xenakis' audible screens (reproduction of fig.II-8, Xenakis 1992, 51).

Xenakis explains in detail how to link the different screens in time using again the cybernetic epistemology described by Ashby. Each screen is represented by letter, a *term* (a, b, c, etc.). As Ashby does in his cybernetics, Xenakis first describes *determinate* transformations and he later introduces *stochastic* ones. A determinate transformation is closed – all the elements of the transformation are predefined – and single-valued – each operant is converted to one and only one transform – (Ashby 1999, 11; 14; 24). Let us take a defined set of screens' transitions describing a sound's transformation. This can be also considered as the actual representation of the sound's history in time, which can be noted as a standard representation (fig.6).

↓	*a*	*b*	*g*	*k*
	b	*g*	*k*	*a*

Figure 6. Transformation of screens (Xenakis 1992, 69).

Xenakis suggests also another use of the cybernetic representation, where the elements of the transformation, instead of screens, can represent other musical elements: notes (fig.7), rhythmic values (fig.8), textural qualities (fig.9), timbres (fig.10) or 'concrete music characters' (Xenakis 1992, 69-71) (fig.11).

↓	*C*	*D♭*	*D*	*E♭*	*E*	*F*	*G♭*	*G*	*A*	*B♭*	*B*
	D	*G♭*	*G*	*C*	*F*	*B*	*A*	*D♭*	*E♭*	*E*	*B♭*

Figure 7. Transformation of notes (Xenakis 1992, 70).

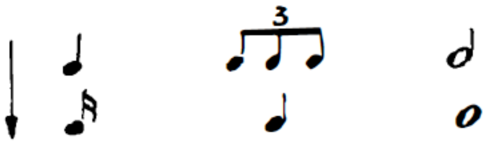

Figure 8. Transformation of rhythmic values (Xenakis 1992, 69).

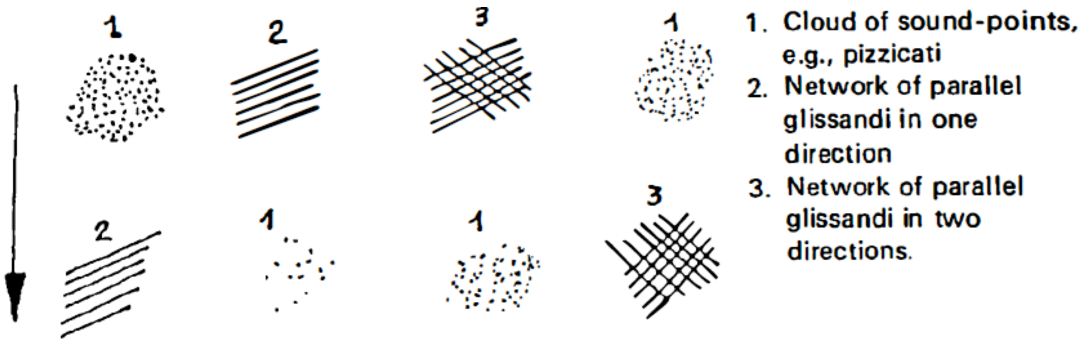

Figure 9. Transformation of textural qualities (Xenakis 1992, 70).

↓	clarinets	oboes	strings	timpani	brass
	timpani, strings	timpani, bassoon	brass	oboes	strings, oboes

Figure 10. Transformation of timbres (Xenakis 1992, 70).

nil	vibrated	trembled	cyclical	irregular
cyclical or trembled	irregular	nil or irregular	trembled	nil or vibrated or cyclical

Figure 11. Transformation of 'concrete music characters' (Xenakis 1992, 71).

Xenakis continues the exposition of his method using stochastic transformations, i.e. where a state can change to another possible number of states through a law of probability (Ashby 1999, 162). As Ashby explains, if in a states' sequence, the probability of each transition is invariable, then we have a Markov chain (Ashby 1999, 166). Then, the term of Xenakis markovian stochastic music derives from the fact that each grain's transition has a constant probability factor. This can be represented by a matrix of transition probabilities like the example of Ashby in fig.12.

↓	*A*	*B*	*C*
A	0.2	0	0.3
B	0.7	1.0	0.3
C	0.1	0	0.4

Figure 12. A matrix of transition probabilities (Ashby 1999, 177).

To make it clear, in the example of fig.12, the element A is 20% possible that it will reappear, 70% that it will become B and 10% that it will be transformed into C. The stochastic transformation is an extension of the determinate one. In other terms, a determinate transformation is a limited case of a stochastic one but were there is only one possible transition from an element to another. This is the case for example, in fig.12, where B is 100% possible it will reappear in each successive transition.

Xenakis' basic hypothesis is directly connected with the creation of timbre, where *second order sonorities* emerge from clouds of audible grains (Xenakis 1963, 65; Xenakis 1992, 103). According to his hypothesis, it is possible to analyse and reconstruct any sound as a combination of myriads of grains, while it is possible to create sounds that have never existed before.[5]

As Di Scipio suggests, the question of second order sonorities can be interpreted through cognitive studies of auditory perception, another aspect of systems thinking (Di Scipio 2001, 72). According to Bregman, concerning the auditory perception, we refer to *emerging properties* when global features appear in a 'higher' organisational level from the grouping of information in a lower organisational level (Bregman 1999, 138). The tendency of the environment is that when elements are organised in a group then new properties appear, in other terms emerging phenomena. Similarly, our perception is interested to find and to process these important structures in order to represent the environment.[6]

Xenakis first applied his hypothesis in his compositions *Analogique A* and *Analogique B* (1958-59). Even though, they are not considered particularly successful results,[7] *Analogique B* can be viewed as the first composition of granular synthesis (Di Scipio 2001, 79). Xenakis with the hypothesis of second order sonorities suggests a new epistemology about musical creation and perception. With the introduction of the probabilistic paradigm along with the cybernetic notion of transformation and consequently with all additional systemic implications, Xenakis opens a new field in music that so far we have managed to explore only to a limited extend.

Why to be interested in systems thinking and Xenakis?

In his discussions about computer music Hamman points out that today there is a general tendency to refer to notions of form and technique dating back to the 19th century (Hamman 1994). Similarly, the methodological approaches are based on the conventional rationalism of thesis and argument or in the tradition of empiricism of experiment and conclusion. He calls the need for a more holistic approach and he underlines the importance of an approach like those of Xenakis and Hiller, as "the incorporation of mathematical theory in music composition was not merely a technique by which new works could be generated -- it represented an epistemological model for composition which allowed them to reconceptualize the process of composition itself" (Hamman 1994).

As mentioned above, Xenakis interpreted the serialists' compositional activities within the field of mathematics and in this way he could make his analysis and critique in a well established field. In addition, by knowing the evolution on the field of mathematics, that is to say that the mathematics of his era were orientated towards statistical operations, he could suggest a progressive step that was already taken in the field of mathematics, that of the probabilistic theory.

The same thing can be said about interpreting the music of Xenakis through systems thinking. First of all we can understand more profoundly his methodologies and the resulting aesthetic values, which can tell more about his music than the simple approach through mathematical formulas. In addition, knowing the evolution of these theories, we can suggest new applications into music. Systems thinking is a field that started to flourish in the middle of 20th century and is still far from being crystallised. There are a lot that we can benefit by looking at the rich work of Xenakis through this perspective, and considering the implications that it has for the present or for the future of composition.

Development of music in a systems thinking framework

As Xenakis places his critique on serialism on a logico-mathematical context, in the same way, Di Scipio calls for a systemic framework for his critique on the electronic music of Xenakis. Di Scipio doubts that the stochastic laws Xenakis is using are able to achieve the emergence of second order sonorities. Summarising the conclusions of Di Scipio for Xenakis mechanism (Di Scipio 2001), as I have already pointed out (Kollias 2009b), we can identify the characteristics of a *closed system*.[8] In addition, Di Scipio interprets the mechanism within the systems thinking framework, having to suggest the application of a more advanced systemic notion, that of the *self-organising system*.[9] In this way, in Di Scipio's model of what he calls *Audible Eco-Systemic Interface,* he is using an updated version of Xenakis's mechanism. This time, the closed system of Xenakis is changed for an open system, a self-organising system. In Di Scipio's approach, all sound operations from the source to the result are taking place during the performance. In this sense, Di Scipio suggests an ecosystemic approach in composition, where the actual space of the performance, including all the sound sources, becomes the environment of the emerging self-organising system. Di Scipio's approach based on Xenakis inside a systemic framework also is an alternative approach of live interactive composition.

In this perspective, the composer programs a Digital Signal Process unit (DSP), which is able to organise its own processes. As the principle of self-organisation suggests, the system takes sound from the environment which analyses perceptually and transforms it in accordance with its properties. Then, the system projects the sound result on the environment, which in turn will influence its next sound-action, as the system will use again the new sound inside the environment. And the feedback loop of perceiving and acting continues.

The aim in Di Scipio's approach is to reduce to the minimum any human direct control that can interfere with the system's spontaneous self-organisation. As Di Scipio puts it (Di Scipio 2003), the composer does not compose the musical result, instead he/she 'composes the interactions' between the self-organising system and the potential environment. The sound result emerges during the performance as a result of these interactions between the self-organising system and the environment. I have extensively talked about the connection of Di Scipio with systems thinking and thus I will avoid repeating it here (Kollias 2007, 2008, 2009b).

During the course of my research on systems thinking and its connection with music composition, I have investigated the music of Xenakis and Di Scipio and the way both composers have been inspired by these theories. Through this exploration, I found many applications of systems theories, which have revealed the possibility of new aesthetical and technical approaches in music (Kollias 2007; 2008; 2009a; 2009b; 2010; 2011), some of which I shall detail below.

In Di Scipio's approach the composer organises the basic organisational elements on a micro-temporal level, what he calls *microstructural sonic design*, while any higher organisational level is left in favour of the occasional dynamics of the environment. Thus, the composer is giving away his control of the overall result. From a systemic perspective, this is a case of one directional bottom-up organisation, where from the interactions in a basic organisational level emerge all higher level organisations. Nevertheless, as Mitchell explains, all adaptive systems preserve balance between bottom-up and top-down processes with an optimal balance shifting over time (Mitchell 2006, chapter 7). As a solution, I have suggested the use of the systemic principle of *equifinality* (Kollias 2009b). In an open system, i.e. a system in direct communication with its environment, including a self-organised system, "the same final state can be reached from different initial conditions and after disturbances of the process" (von Bertalanffy 2006, 143). My hypothesis was that "if we consider the music organism as an open system, *it is possible to create certain conditions in which the organism will show tendency for 'equifinal' behavioural states"* (Kollias 2009b, chapter B). In other terms, the composer can "*influence the system in order to pass from a series of behavioural states, which can be similar in any constitution of the same organism under similar circumstances"* (Kollias 2009b, chapter B).

In my work *Ephemeron* (2008), I have created an algorithm, like a genetic code, from which emerges a live music organism during the performance. This organism has always the same general structure determined by perceptibly similar characteristics, yet it reacts always differently according to the circumstances. Like a plant that we can always identify as the same species but which always develops differently according to the circumstances.

Another development in the way that Xenakis and Di Scipio have curved, is a general model of what I call *self-organising music*: 'the result of the interactions between some predefined structures and an occasional context of performance, through a particular interpretational model' (Kollias 2009b, chapter F).[10] To go even further, we can reinterpret the whole concept of the musical work through the perspective of the self-organising work. Even music of the fixed medium, even if it is composed in a studio situation or from a live recording, shows characteristics of an open system. As I have wrote before, "[e]very time it is diffused, the work's constitution depends on the particular characteristics of the playback system, the acoustic characteristics of space, not to mention the particular social context and the psychosomatic state of each and every individual" (Kollias 2011, 196).

Conclusion

This article has highlighted aspects of the connection between Xenakis and systems thinking and the general benefits of a systemic framework in musical composition. The influence of systems thinking is fundamental in today's organised thought in general, and in the formation of Xenakis' aesthetics in particular. As a result of his application of stochastics through a cybernetic epistemology, Xenakis has opened a new form of musical creation and experience.

Xenakis' ideas and music can be understood more profoundly through a systemic view, which as we have seen is more substantial than a simple mathematical approach - by investigating the line of evolution of such theories the potential for new musical applications become apparent. Aspects of such applications where briefly demonstrated in connection with my music and that of Di Scipio's.

In short, here I have attempted to provide an overview of the benefits of a systemic approach to the interpretation of Xenakis's music in particular and to music in general.

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Endnotes

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[1] "[l]e côté quantitatif et géométrique de toute musique, devient, avec l' École de Vienne, prépondérant" (translation by the present author).

[2] "la moyenne statistique des états isolés de transformation des composantes à un instant donné" (translation by the present author).

[3] "j'ai trouvé que des transformations qui sont à la base de la cybernétique, je les ai déjà pensées et utilisées dans les Metastaseis, sans savoir alors que je faisais de la cybernétique!" (translation by the present author).

[4] Although Xenakis' use of the method is not wrong, confusion has to be avoided as Xenakis uses the arrow that originally signifies transformation in order to describe just a simple mapping.

[5] The hypothesis of second order sonorities is based on Gabor's theory of the representation of acoustic signals. Notably, it seems that Gabor knew the work of Wiener, one of the founders of cybernetics, while he had presented his theory of acoustical quantum in a series of lectures at MIT while Wiener's had a teaching position there (Roads 2001, 63).

[6] It has to be noted that one of the fundamental hypothesis of the science of perception is the existence of an external world, the environment, which is represented internally through out perception.

[7] According to Xenakis concerning *Analogique A* "a realization with classical instruments could not produce screens having a timbre other than that of strings because of the limits of human playing. The hypothesis of a sonority of a second order cannot, therefore, be confirmed or invalidated under these conditions" (Xenakis 1992, 103). Similarly Di Scipio discussing *Analogique B*: "Just as the pizzicatos of *Analogique A* could not but remain string pizzicatos, however dense their articulation, the electronic grains in *Analogique B* remain just grains and do not build up into more global auditory image" (Di Scipio 2001, 73).

[8] According to von Bertalanffy, closed are the systems "which are considered to be isolated from their environment" (von Bertalanffy 2006, 39).

[9] As the term suggests, a self-organising system is a system able to organise its own function.

[10] I first discussed about self-organising music in: Kollias 2009b. For a detailed discussion about self-organisation and music see: Kollias 2011.