



HAL
open science

Analytical Approches to Tauriphanie dans Voyage Absolu des Unari vers Andromède by Iannis Xenakis

Pierre Couprie

► **To cite this version:**

Pierre Couprie. Analytical Approches to Tauriphanie dans Voyage Absolu des Unari vers Andromède by Iannis Xenakis. Peter Weibel; Ludger Brümmer; Sharon Kanach. From Xenakis's UPIC to Graphic Notation Today, Hatje Cantz Verlag, pp.434-457, 2020, From Xenakis's UPIC to Graphic Notation Today, 978-3-7757-4741-7. hal-02546819

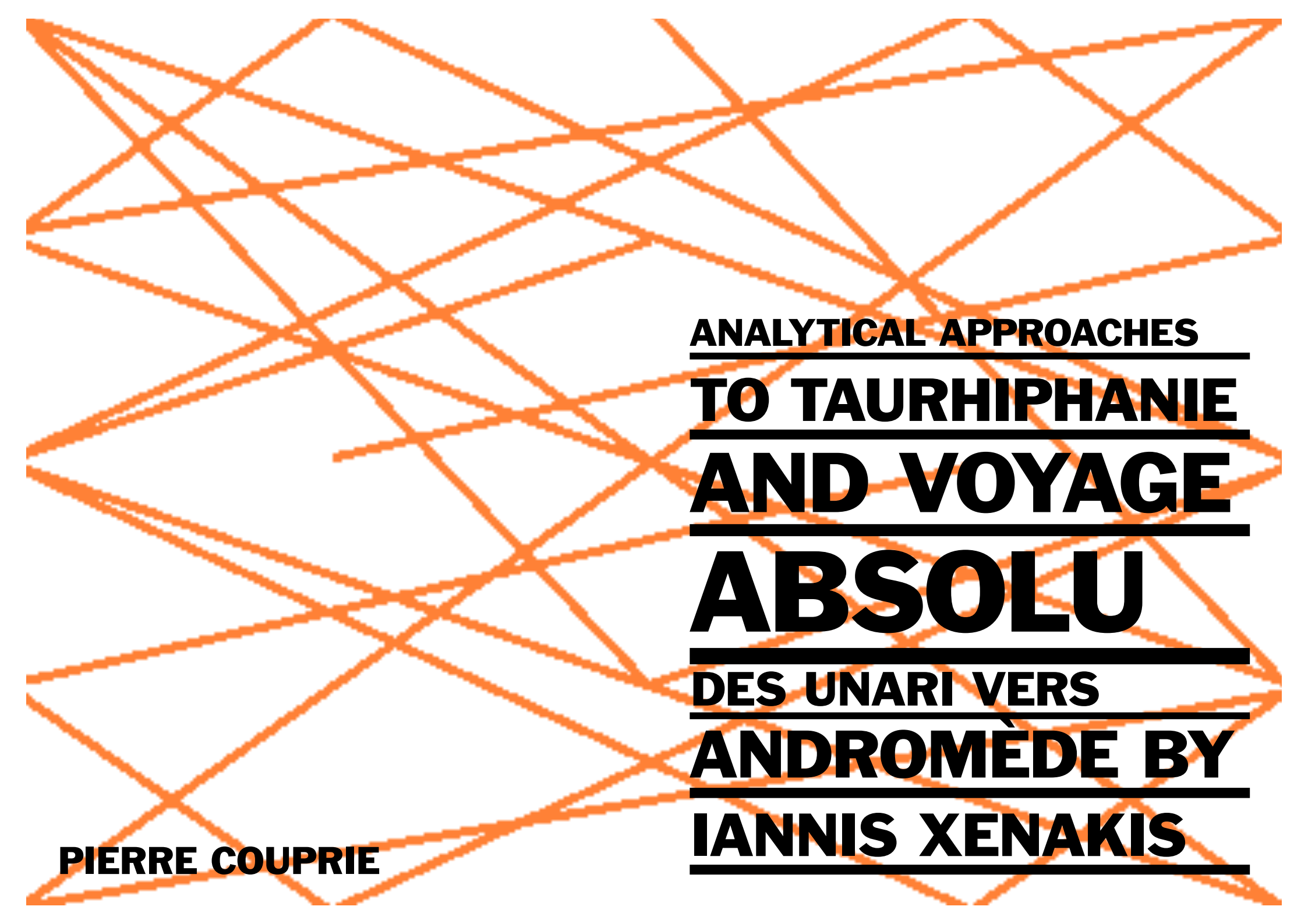
HAL Id: hal-02546819

<https://hal.science/hal-02546819>

Submitted on 18 Apr 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



ANALYTICAL APPROACHES
TO TAURHIPHANIE
AND VOYAGE
ABSOLU
DES UNARI VERS
ANDROMÈDE BY
IANNIS XENAKIS

PIERRE COUPRIE

ANALYTICAL APPROACHES TO TAURHIPHANIE AND VOYAGE ABSOLU DES UNARI VERS ANDROMÈDE BY IANNIS XENAKIS

INTRODUCTION

Iannis Xenakis's electroacoustic work represents only a small percentage of his musical production. However, as Makis Solomos points out, these fourteen works represent real milestones, "masterpieces of absolute originality and innovation"^[1] in the history of electroacoustic music. But, beyond this often-emphasized originality, Iannis Xenakis seems also to have provided a true model for music research. By transposing the methods of scientific research into the field of artistic creation, he created a new discipline that combines the logic of mathematics, the empiricism of computer sciences, and the creativity of arts.

It is standard practice to classify the composer's electroacoustic production into three time periods:^[2]

1. Works from the 1950s and 1960s representing the production carried out by or under the influence of the Groupe de Recherches Musicales (GRM).
2. The "climax of the early 1970s" with the realization of *Polytopes* between 1967 and 1978.
3. The works of the late 1980s composed with the UPIC.^[3]

The analytical research of this chapter concerns this last period and focuses on two emblematic works, rarely presented and analyzed: *Taurhiphanie* (1987) and the *Voyage absolu des Unari vers Andromède* (1989). It is difficult to find sources,^[4] and there is a very important difference between concert versions and those released on CD, but the technical context of their production or the surprising strangeness of their sound and musical rendering make it an exciting field of research for the musicologist. I will show that these characteristics are obviously strongly

linked to the UPIC, the instrument on which Xenakis worked both as a designer and as a user for the composition of these works.

Analyzing an electroacoustic work presents several difficulties, such as the lack of visual support (score, transcription, or other), the study of the complexity of materials, and the predominance of nonrepetitive, evolutive forms. To solve these difficulties, I will use acoustic analysis and visualization techniques already proven in my previous publications.^[5] After introducing some background information on the UPIC and the few sources that exist on the creation of these two works, I will develop the essential points for understanding the analytical method, and then I will present the first results of the comparative study.^[6]

CONTEXTS THE UPIC SYSTEM

For a detailed presentation of the UPIC, I invite the reader to consult three seminal papers: the article by Gérard Marino, Marie-Hélène Serra, and Jean-Michel Raczinski which focuses on a description of the functional aspects of the instrument;^[7] the introduction to drawing techniques and their sound rendering by Iannis Xenakis;^[8] and the article by Rodolphe Bourotte and Cyrille Delhayé with a perspective on the UPIC and its uses in education and with other technologies.^[9] In the history of computer music, which usually begins with the MUSIC software, the first version of which was released in 1957,^[10] or the development of digital instruments from the 1970s, the UPIC appears to be one of the most important tools. Indeed, although its use remained rather confidential, limited to a certain number of studios, its concept, based on converting a drawing into a synthesis sound,^[11] has inspired many developers. The pedagogic^[12] and artistic potential of image conversion into sound makes this instrument so powerful.^[13]

The first versions of the UPIC^[14] were not in real time,^[15] which made it a composition tool for studio use. The first real-time version of 1987 allowed some form of interaction and could therefore be used live, in concert. The UPIC appears to be a very innovative instrument, combining composition functions, a graphical user interface that was easy to use by composers or even children, and a live performance capability using a gestural interface.^[16] These characteristics prefigured current music creation software. By comparison, the other two main tools developed in the 1970s and 1980s in Paris, namely, the 4X^[17] at IRCAM and SYTER^[18] at GRM, were essentially sound transformation tools which could be used as well for mixed works that combined acoustic instruments with electronic sounds.

These few technical details about the instrument itself are also related to sound rendering. The UPIC differed from other technologies of the time. As James Harley^[19] and Makis Solomos point out in their

discussion of *Pour la Paix*,^[20] the sounds produced by the UPIC may seem harsh because the composer does not try to smooth out the result. This remark obviously echoes other works by Xenakis, such as *Bohor*, composed in 1962.

CREATION OF THE WORKS

I have chosen to analyze *Taurhiphanie* and *Voyage absolu des Unari vers Andromède* by Xenakis for several reasons. The first is that they were composed two years apart, in 1987 and 1989. Being electroacoustic works, they were both composed on the UPIC system. Another reason is that they share the same process of creation and publication: the recordings released on CD are very different from their performance in concert. Finally, there are very few sources that allow us to understand the composition process used by the composer. *Taurhiphanie* and the *Voyage absolu des Unari vers Andromède*, therefore, appear to be ideal for comparative analysis. However, this chapter is not a reference analysis, but rather proposes a few guidelines to understand the aesthetic issues that these two works represent.

Taurhiphanie was premiered on July 13, 1987, at the Arles arena during the Radio France Festival in Montpellier. The performance combined electronic music and a peaceful demonstration of bulls and horses from the Camargue region. The concert also included a performance of *Les Pléiades* (1978) and *Psapha* (1975) by Les Percussions de Strasbourg and the Ensemble Pléiades conducted by Silvio Gualda.

The set **FIG. 1** consisted of a circular raised stage in the middle of the arena on which the UPIC was installed and around which the animals circled. The work included fixed and improvised parts from sixty fragments manipulated in real time by playback with variation of sequences and by effects such as freezing^[21] or reverse. In the original concept, the bulls were to be equipped with high frequency (HF) microphones to capture their breathing; the UPIC would then also have been used to manipulate these sounds in real time. It turned out that the lack of rehearsal time and the movement of animals, which was difficult to control because of the intensity of the sounds diffused, led Xenakis to use prerecorded live sound playback.^[22] The performance did not have the expected success.

In 1988, Iannis Xenakis produced a stereophonic version for four loudspeakers containing only the fixed parts. The work was released on CD in 1994.

As James Harley points out,^[23] *Taurhiphanie* differs from *Mycènes Alpha*, also composed on the UPIC, in the continuity of its transformations and its formal construction.

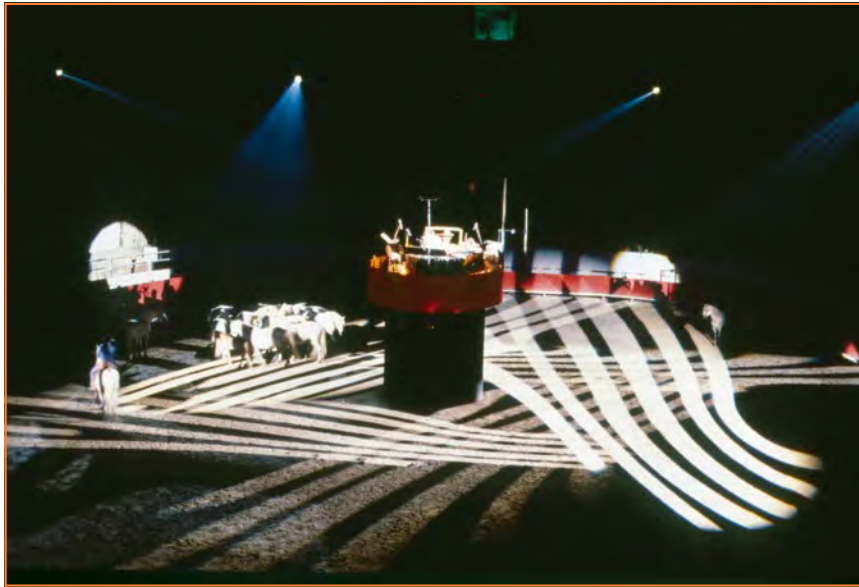


FIG. 1 Iannis Xenakis, *Taurhiphanie*, 1987, during the performance at the Arles arena
© Iannis Xenakis Family

The sources used for the analysis include a score and audio recordings as shown in the table below.^[24]

TYPE	SOURCE	DURATION	INFORMATION
26 Photos	IXF		Taken before and during the concert
Text	IXF		Publisher's tape notice
Drawing	CIX		Tape structure with start of improvisation
Printed matter	CIX		Page 30 of the score (unreadable)
Audio	CD	10'53"	CD edition ^[25] – stereophonic
Digitized audio tape	BNF	3'41"	Inscribed: "mounted bulls sequence tape" (in English) – monophonic – June 28, 1987 This may be the tape used during the concert to replace the real-time recording of the bulls.
Digitized audio tape	BNF	6'45"	With a mention of "Right track. Non-final version. Ready for editing with amorces and mixing" (in French) – monophonic – July 13, 1988 Contains three sequences that are also on the CD version.
Digitized audio tape	BNF	8'08"	With a mention of "Left track. Non-final version. Ready for editing with amorces and mixing" (in French) – monophonic – July 13, 1988 Contains three sequences that are also on the CD version.

The *Voyage absolu des Unari vers Andromède* was premiered on April 1 1989 at the Kamejama Hon'yokuji Temple as part of the International Kite Exhibition organized by the Goethe-Institut in Osaka, Japan. It was premiered in France a few months later during the Festival d'Avignon in the main courtyard of the Palais des Papes in a program that also included *Rebonds A and B*, *Idmen A and B*, as well as improvisations by Michel Portal and Bernard Lubat. The title, *Voyage absolu des Unari vers Andromède*, refers to traditional Japanese unari kite bows, simple one-string aeolian instruments which produce a sound arch vibrating in the wind that resembles the chirping of insects.

As with *Taurhiphanie*, the sources used for the analysis include a score and audio recordings as shown in the following table.

Unlike *Taurhiphanie*, the UPIC "score" of *Voyage absolu* was an invaluable help in understanding some aspects of Xenakis's creative process.

VOYAGE ABSOLU DES UNARI VERS ANDROMEDE

partition

Cette partition est constituée des pages dessinées sur l'UPIC au CEMAMu (*). Elle a été suscitée et commandée par le Dr. Paul EUBEL, directeur du Goethe-Institut d'OSAKA au JAPON pour l'inauguration de l'exposition internationale des cerfs-volants, le 1er Avril 1989. Elle lui est dédiée.

Il s'agit d'un voyage spatial dans un lointain avenir vers la galaxie d'Andromède, avec des épisodes pendant les traversées des espaces sidéraux.

La musique, d'une durée de 12'30", est sur bande stereo 1/4 pouce en 38 cm/s et doit être diffusée sur plusieurs haut-parleurs de haute qualité. Les canaux gauche et droit doivent être diffusés par des haut-parleurs reliés en diagonales. Les haut-parleurs entourent le public. Au moins 4 haut-parleurs doivent être prévus, A, B, C, D (diagonaux AC, BD).

(*) L'UPIC est le système informatique qui permet de composer la musique uniquement par le dessin de pages, telles que les pages de cette partition. L'UPIC est créée et produite par le CEMAMu (Centre d'Etude de Mathématique et Automatique Musicales).

TYPE	SOURCE	DURATION	INFORMATION
Score (15 pages)	IXF		A notice FIG. 2 and 12 pages of the drawing realized on the UPIC (pages: 61, 62, 30, 35, 36, 34, 33, 33, 38, 9, 31, 32, 66[26])
Audio	CD	15'29"	CD edition[27] – stereophonic
Digitized audio tape	BNF	12'49"	With a mention of "A version" (in French) – stereophonic
Digitized audio tape	BNF	12'39"	With a mention of "Demo examples" (in French) – stereophonic Contains examples from the UPIC and a long extract from <i>Taurhiphanie</i>

THE ANALYSIS METHOD

Both works are perfectly adapted to the methods of analysis that I usually use on acousmatic music.[28] These are works on magnetic tape and whose sources contain only fragmentary parts of the UPIC score. It was therefore necessary to use other types of graphic supports for this study. As the works are very close in time to each other, and also in terms of the tools used and the compositional approach used for CD publishing (sources of the creation are recomposed in the studio), a comparative analysis is completely justified and makes it possible to show how Xenakis made different compositional and aesthetic choices from fairly similar material.

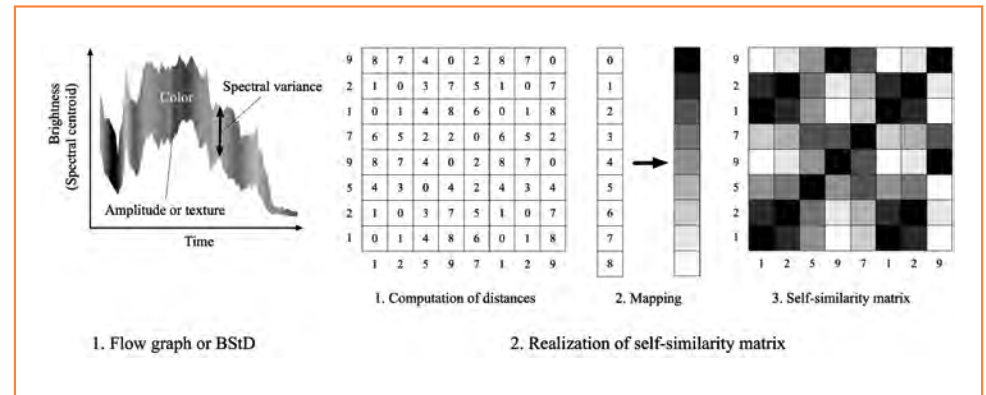
As I mentioned briefly in the introduction, analyzing a fixed work is quite difficult. I have already presented and analyzed in detail the problem of the lack of visual support in several of my publications.[5] For the analysis of the two works in this article, I used spectral representation and audio descriptor extraction techniques to create visualizations that decomposed the sound textures into musical gestures and, in the case of the *Voyage absolu des Unari vers Andromède*, contextualized the fragments of the score.

The techniques of audio descriptor extraction from the audio signal used here have already been described in detail in an analysis of an extract from *Son Vitesse-Lumière*[29] by François Bayle.[30] To summarize: a set of audio descriptors[31] are extracted, either directly from the signal or through spectral analysis achieved with a fast Fourier transform (FFT) algorithm.[32] A representation (visualization) is then made to allow the data to be read.[33]

The visualization part is essential because it is the source of the interpretation that the musicologist will use to make the analysis. I used four visualization techniques that are particularly efficient for musical analysis:

1. The simple graph (morphology identification) or the superposition of curves (correlation identification between values);
2. The flow graph or Brightness, Standard Deviation graph (BStD)^[34] (see FIG. 3.1), allowing to visualize an estimation of the evolution of the timbre through 3 descriptors. This graph is particularly efficient for the analysis of electroacoustic music by facilitating the interpretation of correlations between descriptors;
3. The linear or logarithmic sonogram;
4. The self-similarity matrix (see FIG. 3.2) representing the similarity between values^[35] (identification of musical structure or form). FIG. 3

**ANALYTICAL
APPROACHES TO
TAURHIPHANIE
AND VOYAGE
ABSOLU DES
UNARI VERS
ANDROMÈDE BY
IANNIS XENAKIS**



As shown in Figure 3.2, the self-similarity matrix is realized in three steps:

1. The creation of the table^[36] and the distance computation. The values to be calculated appear on the x-axis and y-axis of the table.
2. The mapping of numerical value results into grayscales (mapping) making the table easier to interpret.
3. In this article, I use color matrices, so the third step is to apply a false color filter.^[37]

These representation techniques are classified into three categories:

1. What I call macroscopies^[38] allowing visualization of the entire work while keeping a view of the complexity of the short structures;
2. Correlation analysis at several hierarchy levels in order to identify the links between the variation of several descriptors;
3. Analysis of internal or external morphologies, both localized or around a focal point.

This representation method has the advantage of allowing analysis without selecting an observation level first. In addition, it also offers the possibility of studying both sound and musical phenomena located on one or more dimensions or that have rather fuzzy borders and are strongly dependent on perception. In this sense, even if I rely heavily on techniques of signal analysis from acoustics or visualizations from the hard sciences, the object observed is not a laboratory sample like an isolated fragment, but the work itself. These researches are naturally in a systemic or complexity^[39] study direction, which seems to me to be the only way to study this type of musical work.

COMPARATIVE ANALYSIS

The presentation of these first analytical results is organized in three parts: forms and segmentations, gestures, and the poles of *continuous-discontinuous*. However, they do not correspond to the stages of the analysis and could just as easily have been presented in a different order.

FORMS AND SEGMENTATIONS

FIG. 4 represents a self-similarity matrix computed on the zero crossing rate (ZCR) of the *Taurhiphanie*'s waveforms. This representation provides a good estimation of the whole form of the work. Vertical band reading can be used to segment the shape into three large parts or eight more detailed parts. In addition, the central part offers a strong contrast with the other parts of the work by being similar to itself (colors close to yellow and red), but not to what comes before or after (purple color indicating a low similarity).

This representation also provides two other important formal clues. The first concerns the duration of the parts. Xenakis seems to have organized the material into fairly long ranges with constant evolution and only a few breaks. The second clue concerns the transitions between each of the parts, which seem quite distinct, thus separating them into well-defined blocks.

FIGS. 5, 6 illustrate the most salient transformation processes and transitions:

1. Transition between two parts including silence.
2. Transition by very short crossfade.
3. Accentuation by amplitude modification or spectrum densification.
4. Long morphological gesture.
5. Coloration by modification of the spectral centroid.
6. Destructuring a material by altering a dimension such as amplitude or spectrum.
7. Tightening of the spectrum.

These two representations are created from three audio descriptors^[40] in a single graph. Correlations between several elements of the curve—for example, *y* and width—and significant changes—for example in figures 4 and 6—highlight salient elements of the spectrum evolution. On all the graphs, there is no real break and this evolution appears to be rather continuous. Also, the two forms do not have repetitions; each part allows to cross a step in a continuous evolution of the sound material, a morphological form.^[41]

James Harley proposes a two-part form segmentation of the *Voyage absolu des Unari vers Andromède*.^[42] **FIG. 7** shows this segmentation as well as the one derived from a two-level listening analysis. These segmentations are compared here with two complementary self-similarity matrices calculated on the FFT and on three audio descriptors root mean square (RMS) amplitude, spectral centroid, and spectral variance. These figures highlight strong similarities between the two works in terms of form construction:

ANALYTICAL APPROACHES TO TAURHIPHANIE AND VOYAGE ABSOLU DES UNARI VERS ANDROMÈDE BY IANNIS XENAKIS

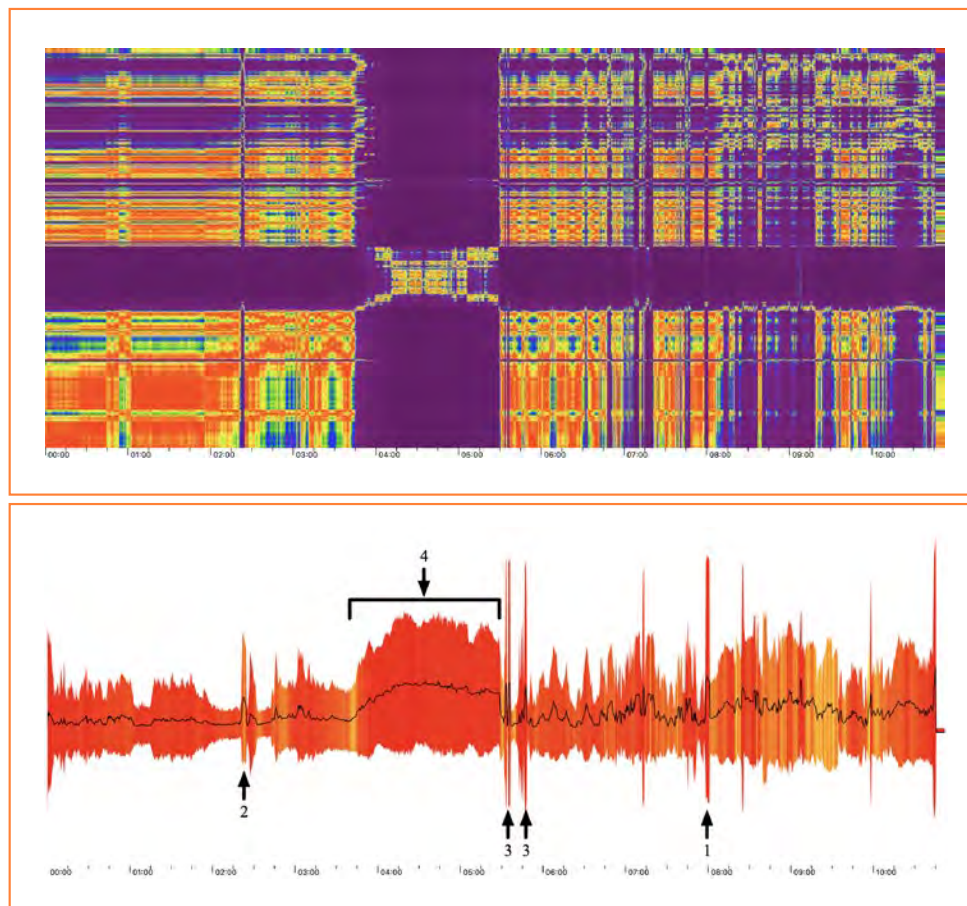


FIG. 4 Self-similarity matrix of Iannis Xenakis's *Taurhiphanie*, 1994, computed on the ZCR descriptor in software iAnalyse, 2019, screenshot © Pierre Couprie

FIG. 5 Four examples of transformation processes from a BSTD representation of Iannis Xenakis's *Taurhiphanie*, 1994, produced with software iAnalyse, 2019, screenshot © Pierre Couprie

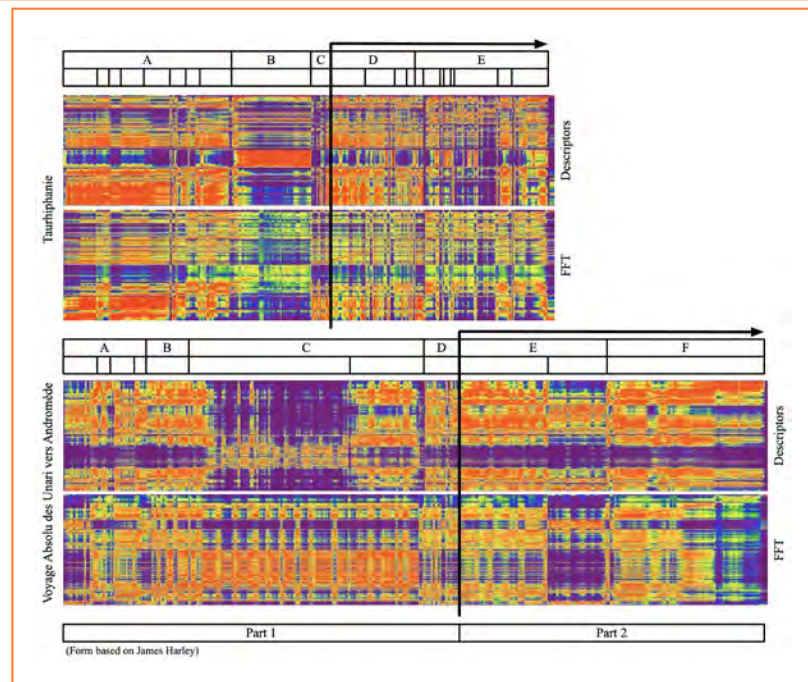
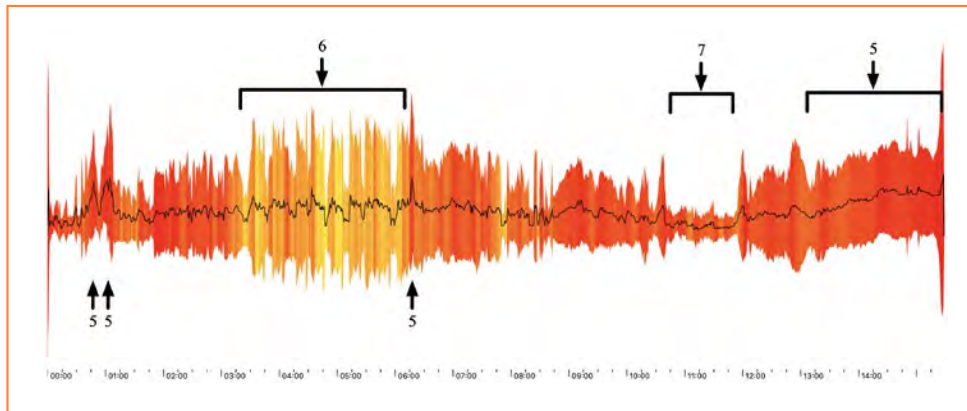


FIG. 6 Three examples of transformation or transition processes from a BStD representation of Iannis Xenakis's *Voyage absolu des Unari vers Andromède*, 1987, produced with software iAnalyse, 2019, screenshot © Pierre Couprie

FIG. 7 The form and comparison between FFT and the audio descriptors as selfsimilarity matrices, produced with software iAnalyse, 2019, screenshot © Pierre Couprie

- An overall division into two parts (indicated by a wide line and an arrow), the second part can itself be subdivided into two other parts.
- The presence of a long part (A in *Taurhiphanie* and C in *Voyage absolu...*) built on a continuous evolution of the sound material.
- The presence of short parts (C in *Taurhiphanie*) and B, D in *Voyage absolu...*) whose duration contrasts strongly with the other parts.

These two works, therefore, appear to be linked in terms of structure while at the same time being the result of very different compositional strategies. However, the form alone is not sufficient for comparative analysis. I will now show how the morphogeneses or gestures^[43] used by Xenakis also play a very important role in the transitions and in the characterization of the subparts.

GESTURES: FROM THE UPIC TO SOUND REALIZATION

As mentioned above, I had access to the score of the *Voyage absolu des Unari vers Andromède*. This consists of twelve drawings on the UPIC.^[44] Considering the numeration of the pages divided between 9 and 60, it is likely that it is only a fragment of the complete score. In addition, pages 32 and 60 are identical and there appear to be only two original drawings (page 32 and 34), the others being variations of page 32. The second original drawing (page 34) did not result in any variations. Figure 8 provides a hypothesis on the realization of these variations. We can see that Iannis Xenakis worked mainly from variations by rotation^[45] and by assembling the same multiplied form (as in pages 9, 30, 38 and in the ones that follow). Finally, few drawings are directly visible and perceptible in the spectrum computed from the CD version. **FIG. 9** shows the spectrum (top) and a schema (bottom) containing the locations of the actual drawings.^[46] I have named A and B the two forms that appear clearly on the spectrum as probably having their origin in a UPIC drawing, but they are not present in the score. Similarly, the fragment 9b comes from page 9, but there is a montage of two additional iterations compared to the original form. The only appearance of page 34 (noted 34b) at 12:03 is, for its part, greatly modified by the effects of multiplication and time stretching.

What is observable in this work is unfortunately not observable in *Taurhiphanie*. Indeed, if the score exists, it has not yet been digitized, and the fragility of the originals have not yet allowed me to work on the identification in the CD version of the shapes drawn on the UPIC. Nevertheless, some of the shapes visible on the spectrum probably come from materials drawn on the UPIC, their appearance being very similar

to those used in the *Voyage absolu des Unari vers Andromède*. While listening to the digitized tapes at the Bibliothèque Nationale de France (BNF), I realized that the waveforms used in the UPIC probably all come from recordings of bulls' roars. In addition, the very short morphologies in glissandi, such as at 2'22", 5'34", between 6'55" and 7'58", or at the end of 8'35" are very similar to some of the roars present on the sound recording tape available at the BNF.

The CD production of these pieces, therefore, appears as a composition in its own right, based on materials partly made on the UPIC. Both of the two pieces can be decomposed to analyze how Iannis Xenakis managed the transitions between materials and the progressive changes in textures.

CONTINUOUS AND DISCONTINUOUS: TRANSFORMATIONS AND TRANSITIONS

In my analysis, I highlighted the composition of the two works as an assembling of several sequences, some of which use materials from drawings on the UPIC. However, during the listening, the editing aspect does not really appear and an impression of moments would be more accurate. Each of them has its own written logic and all these moments follow one another without any real break. This first form of continuity is particularly visible on the complete logarithmic spectrum of each piece. **FIG. 10**

In *Taurhiphanie*, except for the central break between 3:48 and 5:28,^[47] the spectrum shows continuity on two types of materials:

1. 0'00"–3'45": A material with a very rich spectrum.
2. 5'15"–End: A rather harmonic set of sounds.

In the *Voyage Absolu des Unari vers Andromède*, the logarithmic spectrum highlights the crossfade transitions chained between three types of sound materials:

1. 0'00"–3'00": material with a rather clear spectrum.
2. 3'00"–8'00": A very rich and dense sound material.
3. 8'00"–End: A set of sounds whose spectral sites are quite narrow.

In the second work, the crossfade transitions between the three types of materials are very evident. These transitions between the main parts also operate at a finer level. Listening to and viewing the sonograms reveals that both works were composed as a montage of several sections on several levels. If Iannis Xenakis uses the crossfade between the large parts, he varies the transitions of shorter sound materials (see **FIG. 11**):

ANALYTICAL APPROACHES TO TAURHIPHANIE AND VOYAGE ABSOLU DES UNARI VERS ANDROMÈDE BY IANNIS XENAKIS

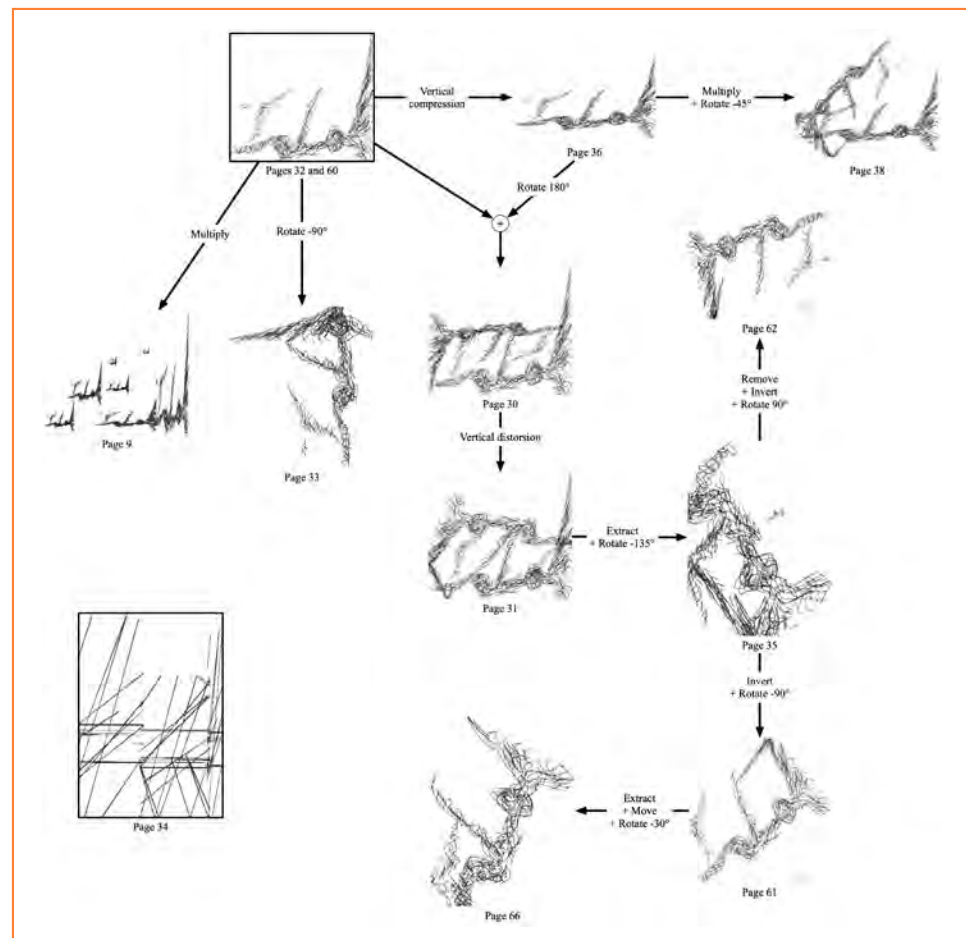


FIG. 8 Hypothesis of the genesis of the score pages from two original shapes (framed) of Iannis Xenakis's *Voyage absolu des Unari vers Andromède*, 1987 © Pierre Couprie

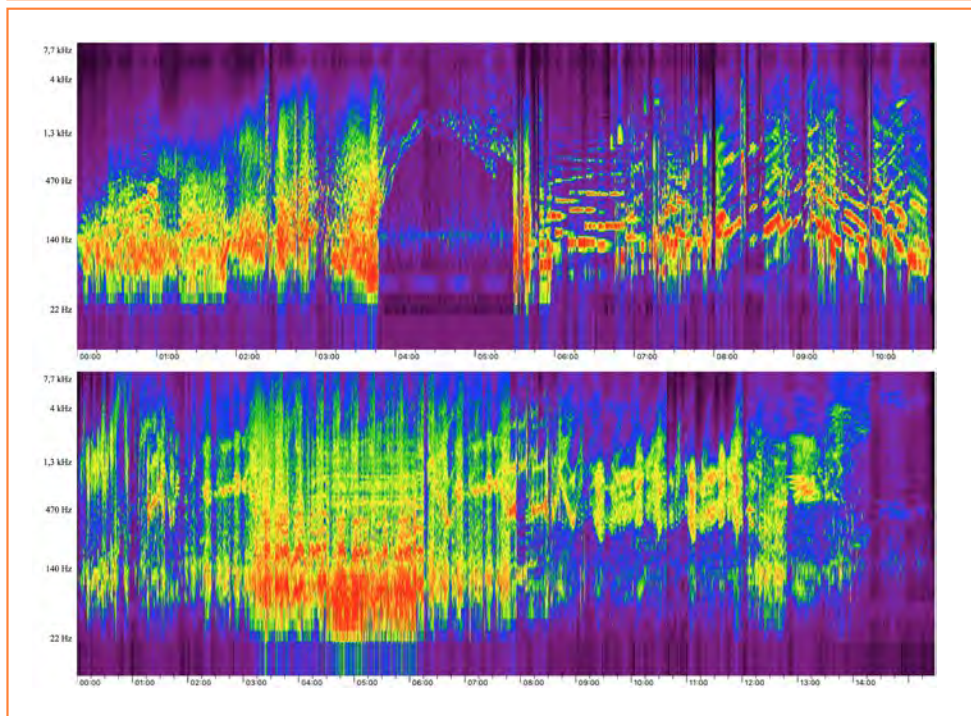
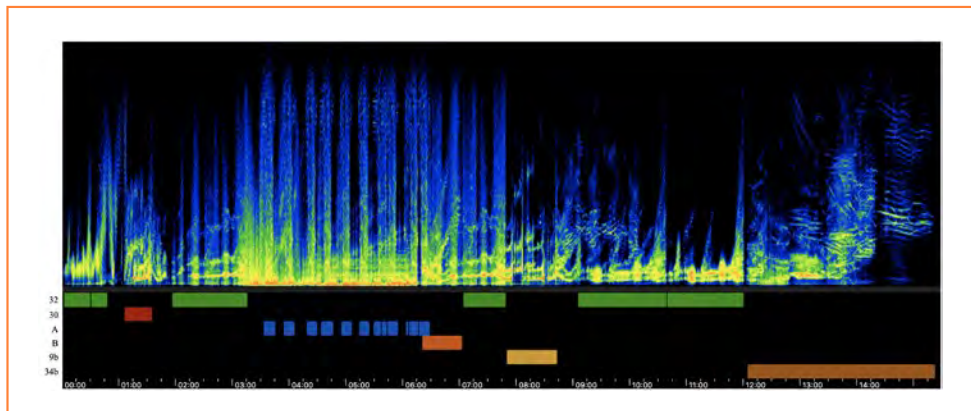


FIG. 9 Time location of the score pages of Iannis Xenakis's *Voyage absolu des Unari vers Andromède*, 1987, produced with software iAnalyze, 2019, screenshot. A, B, are missing gestures in the score and 9b and 34b are variations of pages 9 and 34. © Pierre Couprie

FIG. 10 Logarithmic spectrums of Iannis Xenakis's *Taurhiphanie*, 1994 (top) and *Voyage absolu des Unari vers Andromède*, 1987 (bottom), produced with software iAnalyze, 2019, screenshot © Pierre Couprie

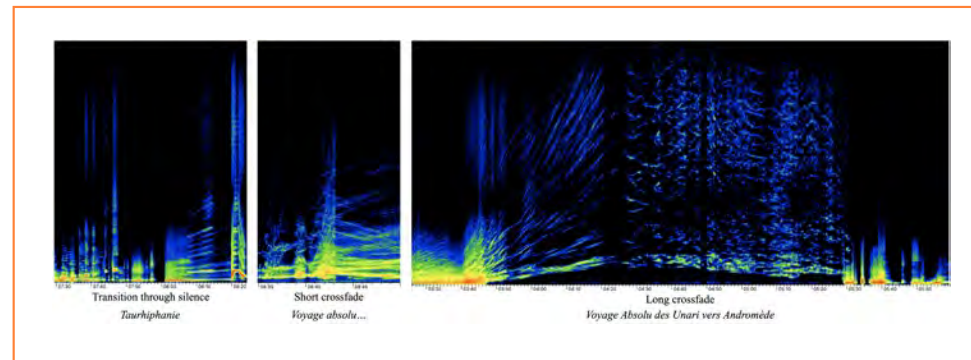


FIG. 11 Examples of transitions by crossfading or by a silence in Iannis Xenakis's *Taurhiphanie*, 1994, produced with software iAnalyze, 2019, screenshot © Pierre Couprie

FIG. 12 Comparison of Iannis Xenakis's *Taurhiphanie*, 1994 (top) and *Voyage absolu des Unari vers Andromède*'s, 1987 (bottom) waveform and deviation between the RMS amplitudes of the two channels in red, produced with software iAnalyze, 2019, screenshot © Pierre Couprie

1. Via a very short silence (1.2 seconds at most) present only in *Taurhiphanie*.
2. By using a very short crossfade.
3. By using long crossfades or progressive transformations of the material. **FIG. 11**

Taurhiphanie, Iannis Xenakis, examples of transitions by crossfading. These transitions, both in large parts and shorter structures, create great continuity in the evolution of form. However, both works also have forms of discontinuities that are revealed in the balance between the two channels. Iannis Xenakis systematized a strong stereophonic oscillation of the material. **FIG. 12** shows the waveforms and a deviation curve of the RMS amplitude^[48] in red.

It can be noticed that the frequency of oscillation is very different in the two works. Even if the one at the top (*Taurhiphanie*) has a greater range of deviation, this oscillation is almost continuous; only *Voyage Absolu des Unari vers Andromède* has some moments of relative stability (around 1'00", 9'30" and 14'00").

Continuity and discontinuity are therefore to be found at several timescales and are complementary to each other. Thus, the de-correlation of the channels allows the composer to obtain a less monolithic material. It is easy to imagine what Iannis Xenakis wanted when he suggested playing these stereophonic versions over four loudspeakers by crossing the channels.

CONCLUSION

In this short paper, I have attempted a first approach at comparative analysis of these two emblematic works of electroacoustic production by Iannis Xenakis. As I have been able to demonstrate, the use of analytical methods based on acoustic representation or visualization of information extracted from the signal has allowed me to study the construction of the works in more detail, and also to propose some hypotheses about the creative process. The exploration of new sources will probably be able to complete these analyses.

If Iannis Xenakis has provided a model for the interaction between mathematics, computer science, and artistic creation, he has also offered us a model for what are known as digital humanities, just as Jean-Claude Risset did. Research on such works cannot be conducted without the interaction between several scientific disciplines and a constant back and forth between research and creation. Through his works, Iannis Xenakis has shown us a very rich path for music research by combining in the same discipline issues that may seem very different, but which contribute to the same goal; the renewal of artistic forms.

FOOTNOTES

1. Makis Solomos, "Introduction," in *Iannis Xenakis, la musique électroacoustique*, ed. Makis Solomos (Paris: L'Harmattan, 2015), 5.
2. Boris Hofmann, "The Electroacoustic Works by Xenakis and Their Instrumental Contemporaries," in *Iannis Xenakis, la musique électroacoustique*, ed. Makis Solomos (Paris: L'Harmattan, 2015), 19–28.
3. UPIC: Unité Polyagogique Informatique du CEMAMu. The UPIC is a digital instrument that allows users to compose by drawing on a graphic tablet. Iannis Xenakis composed four works on UPIC: *Mycènes Alpha* (1978), *Pour la Paix* (1981), and the two works analyzed in this chapter.
4. I would like to thank Mâkhi Xenakis, Sharon Kanach, Cyrille Delhayé (GRHis), and Pascal Cordereix (BNF, Bibliothèque Nationale de France) for all the help they gave me in consulting parts of the sources.
5. Pierre Couprie, *L'analyse musicale et la représentation analytique de la musique acousmatique: Outils, méthodes, technologies*, Habilitation Thesis (Paris: unpublished manuscript, 2015); Pierre Couprie, "Prologomènes à la représentation analytique des musiques électroacoustiques," in *Circuit 25*, no. 1 (2015), 39–54; Pierre Couprie, "Analyse de la musique mixte: Logiciels, procédures, workflows," in *Analyse de la musique mixte*, ed. Alain Bonardi, Bruno Bossis, Pierre Couprie, and Vincent Tiffon (Paris: Delatour, 2017), 61–79; Pierre Couprie "Nouvelles approches audio-numériques pour l'analyse musicale." in *Musicologies nouvelles 5* (2018), 120–132.
6. Representations, whether of the signal, its analysis, its decomposition into descriptors or graphs and transcriptions, have been made on the iAnalyse 5 software developed for musical analysis assistance (<http://ianalyse.pierrecouprie.fr>).
7. Gérard Marino, Marie-Hélène Serra, and Jean-Michel Racziński, "The UPIC System: Origins and Innovations," in *Perspectives of New Music 31*, no. 1 (1993), 258–69.
8. Iannis Xenakis, "Determinacy and Indeterminacy," in *Organised Sound 1*, no. 3 (1996), 143–155, here 150–52.
9. Rodolphe Bourotte and Cyrille Delhayé, "Learn to Think for Yourself: Impelled by UPIC to Open New Ways of Composing," in *Organised Sound 18*, no. 2 (2013), 134–45.
10. The MUSIC software was developed by Max Mathews from 1957 at the Bell Telephone Laboratories on an IBM 704. It is referred to as MUSIC I.
11. This idea had already been partially put into practice by Larry Rosler and Max Mathews who had developed a graphic system in 1966 to draw the frequency and amplitude of synthesized sounds (see Jean-Claude Risset, "Recollections and Reflections on Organised Sound," in *Organised Sound 20*, no. 1 (2015), 15–22, here 18.).
12. Anastasia Georgaki, "Sound Pedagogy Through Polyagogy: Initiation to Xenakis' World in Primary School Through the HighC Interactive Whiteboard," in *Iannis Xenakis, la musique électroacoustique*, ed. Makis Solomos (Paris: L'Harmattan, 2015), 241–54; Malika Combres, "La musique contemporaine à l'école," in *Transposition*, no. 2 (2012), 23–31, <http://journals.openedition.org/transposition/462>
13. Maria Harley, "Musique, espace et spatialisation. Entretien de Iannis Xenakis avec Maria Harley," in *Circuit 5*, no. 2 (1994), 9–20, here 12.
14. The first version of the UPIC was completed in 1977.

15. In other words, the time required to calculate and generate sound is far greater than the few milliseconds that give the illusion of real time used in live music.
16. Marlon Schumacher and Marcelo M. Wanderley, "Integrating Gesture Data in Computer-aided Composition: A Framework for Representation, Processing, and Mapping," in *Journal of New Music Research* 46, no. 1 (2017), 87–01, here 88–89.
17. The 4X processor is the result of development carried out by Giuseppe Di Giugno and IRCAM researchers. It was finalized in 1981 and marketed in 1984.
18. The SYTER system (Système Temps Réel) was developed at the Groupe de Recherches Musicales by Jean-François Allouis in 1978.
19. James Harley, "The Electroacoustic Music of Iannis Xenakis," in *Computer Music Journal* 26, no. 1 (2002), 33–57, here 53.
20. Makis Solomos, "L'équilibre fragile de Pour la Paix," in *Iannis Xenakis, la musique électroacoustique*, ed. Makis Solomos (Paris: L'Harmattan, 2015), 127–57.
21. Freezing consists in stopping the advance of the playback head without stopping the sound. The reading is then performed by the playback of a multitude of sound grains located around the position of the playback head.
22. James Harley, "The Electroacoustic Music of Iannis Xenakis," in *Computer Music Journal* 26, no. 1 (2002), 33–57, here 52–53.
23. *Ibid.*, 53.
24. Only audio recordings were used for musical analysis. The abbreviations in the source column stand for: IXF: Iannis Xenakis Family; GRHis: History research laboratory (France, Rouen); CD: CD Edition; BNF: Bibliothèque Nationale de France.
25. Iannis Xenakis, *Aïs – Gendy3 – Taurhiphanie – Thalleïn* (Neuma Records, 1994).
26. The order is the same as that of the PDF document of the sources.
27. Iannis Xenakis, *Musique électroacoustique* (Fractal Records, 2001).
28. Acousmatic music is generally associated with composers from France or abroad related to the GRM. Even when it refers to music composed in a studio on a medium and diffused entirely on loudspeakers in concert, it is difficult to describe some of Xenakis's works as "acousmatic music." The filiation would rather be from computer music.
29. Pierre Couprie, "Voyage dans Grandeur nature," in *Son Vitesse-Lumière*, ed. François Bayle (Paris: Magisson, 2016), 47–57.
30. On this point, the three works present a certain similarity in terms of form, even though the composition techniques are very different. They share the idea of a continuous sound flow articulated by strong morphologies or musical gestures.
31. The descriptors used are mostly low level: RMS amplitude, zero-crossing rate (ZCR), spectral centroid, spectral variance, spectral deviation, inharmonicity.
32. Unless otherwise specified, the FFT computation parameters for extracting audio descriptors are: Window size = 2018, Window type = hanning, Window step = 25 %.
33. The visualization is obtained by converting the list of numerical values into a diagram or by converting the numerical values into color values (mapping).
34. Mikhail Malt and Emmanuel Jourdan, "Le BStD: une représentation graphique de la brillance et de l'écart type spectral, comme possible représentation de l'évolution du timbre sonore," in *L'analyse musicale aujourd'hui*, ed. Xavier Hascher, Mondher Ayari, and Jean-Michel Bardez (Paris: Delatour, 2015), 111–28.

35. It therefore does not represent the values themselves, but their distance.
36. I utilize here the term used in computer science (table); in mathematics we use the term matrix. A matrix is called self-similarity when the computation is based on only one set of values.
37. This step is not trivial, as it compensates for the graphic aberrations caused by grayscale visualization. The coloring generally used is a gradient close to the light spectrum.
38. In reference to Joël de Rosnay's macroscope, see Joël de Rosnay, *The Macroscope: A New World Scientific System* (New York: Harper & Row, 1979).
39. On these questions, I refer to Abraham Moles, *Les sciences de l'imprécis* (Paris: Seuil, 1990); Edgar Morin, *On Complexity* (New York: Hampton Press, 2008).
40. The graph represents: y = spectral centroid, width = spectral variance, color = ZCR.
41. John Young, "Forming Form," in *Expanding the Horizon of Electroacoustic Music Analysis*, ed. Simon Emmerson and Leigh Landy. (Cambridge: Cambridge University Press, 2016), 58–79, here 61.
42. James Harley, "The Electroacoustic Music of Iannis Xenakis," in *Computer Music Journal* 26, no. 1 (2002), 33–57, here 54.
43. Philippe Lalitte points out the impact of the gesture on the perception of form; see Philippe Lalitte, "Conditions de possibilités d'une rhétorique formelle perçue," in *Intellectica* 48–49 (2008), 103–14, here 104.
44. There are thirteen drawings, but pages 32 and 60 are the same.
45. The rotations shown in Figure 8 are approximate.
46. It is, of course, possible that there may be others, masked by transformations.
47. As transitions are made by crossfades, the times shown here and in the following lists are approximate.
48. The deviation between the two RMS amplitude graphs shows the balance of the levels: 1 (bottom) = predominance of the right channel, 0 (middle) = balance between the two channels, +1 (top) = predominance of the left channel.