Notes on Composing with the UPIC System: The Tools (Equipment) of Iannis Xenakis

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The UPIC system, conceived by Xenakis and developed at the CEMAMu, is a computer based composition tool that permits graphical entry of a score. With the UPIC, the user may affect the various levels of digitized sound simultaneously, within the context of a real-time reactive environment. We present a summary of work and research performed on the UPIC by the author during 1995-97 at Les Ateliers UPIC. Specifically, we explore the micro-compositional possibilities and real-time operation of the UPIC, illuminating aspects of today's system with respect to the system used by Xenakis in the 1970's and 80's. We suggest that the combination of real-time operation, and the ability to manipulate the microcompositional level of the digitally represented sound via non-linear functions, provides the opportunity to realize what Xenakis had at one time described as "...not a sound that is produced, but a whole music in macroscopic form."[1]

Xenakis' Micro-Composition

The idea for the UPIC[2] had its origins in the period when Xenakis had composed *Metastasis*, and can be considered an extension of his approach to the problem of composing large-scale structure and form of sound. [Xenakis 1985, Marino 1993, Varga 1996] His treatment of sound could be divided into two principal endeavors: the definition of low-level material, or micro-composition, and the construction of higher-level form, or macro-composition. Concerning the UPIC system, as we shall see, although the user has had the ability to define the lower level source material of the sound, the system was most often utilized to define broader macro-formal structures. Regarding the lower levels of compositional methods, Xenakis has explained, "Outside of work on the UPIC, we are exploring the region of algebraic micro-composition according to non-Fourier methods, rather than Fourier-type methods such as Music V, to which most other laboratories limit themselves." [Xenakis, 1985]. This long-standing project of

[1] Iannis Xenakis, "Music Composition Treks", in *Composers and the Computer*, Curtis Roads, ed., 1985, William Kaufmann, Inc., p. 180.
[2] Unité Polyagogique d'Informatique du CEMAMu.

Xenakis had its genesis in the S/T program first implemented in 1956-62 for instrumental ensembles, and culminating in his more recent tape pieces of the Gendyn project [Xenakis 1992, Serra 1993, Hoffmann 1996], a very original example of non-standard sound synthesis. For Xenakis, the UPIC represented a way for the uninitiated to enter the world of composing sound in mass structures, where graphical design provided the access point to such sounds and structures.

In his computer music and electroacoustic work, Xenakis' approach to micro-composition has entailed the direct manipulation of the synthesized sound. He has suggested several ways of accomplishing this task [Xenakis 1985], among them: (1.) harmonic synthesis using periodic trigonometric functions, (2.) synthesis through the use of aperiodic Brownian functions, and (3.) synthesis using any given function at all, and then applying probabilistic variations to such functions. In all cases, Xenakis stresses the requirement that such functions must repeat, and in the course of the sound's generation, in order for them to remain interesting, judicious modifications must be made at the various levels of the sound – starting at the micro-level, through the intermediate, onto the large-scale macro-level. How can a composer effectively control or specify such changes at all these levels simultaneously? It is worth directly quoting Xenakis' answer to this question in full, as he describes the technique he implemented when composing the music for the Diatope (*Le Legend d'Eer*, 1977):

> "I will cite an interesting example belonging to a case I was able to discover sometime ago by using the logistic probability distribution. For certain values of its parameters α and β and its elastic barriers, this distribution goes through a sort of stochastic resonance, through a most interesting statistical stability within the sound produced. In fact it is not a sound that is produced, but a whole music in macroscopic form, giving a polyrhythm of events with variable timbre, changing pitches and intensities – in short, rhythmic strands and jostling sounds." [Xenakis 1985]

Xenakis' discovery has since been recognized in the literature, and is known by various terms, of which "sonological emergence" is one [DiScipio, 1994]. The combination of the various non-linear processes involved in this synthesis technique (originating in the specification of the logistic probability distribution as a sample generating function) permits such a gestalt to manifest at the macro-level of the sound. This process was not present in the compositions Xenakis created with the UPIC system. Indeed, the initial versions of the system did not provide for the specification of such non-linear processes. It was not until frequency modulation was implemented as a synthesis/transformation technique in the UPIC that non-linear processes were then available to the user. And even then, an implementation of the FM option by the composer did not guarantee that such processes as Xenakis describes above would emerge.

The UPIC System as a Non-Standard, Non-Linear Synthesis Instrument.

The present UPIC does permit the configuration of complex and non-standard FM algorithms. Here we present pertinent details of the UPIC's operation in order to explicate the manner in which frequency modulation is implemented in the system, as well as how one can effect the micro-structure of the digitized sound. During the two-year period between 1995 and 1997, the author has systematically investigated various FM algorithms and configurations on the current UPIC system. We present an account of this work, which ultimately culminated in the composition *Maya*. Throughout, we shall stress the relationship and interdependency among the micro-, intermediate, and macro-levels of the sound, as well as their influence on the resulting sound in the form of the final composition.

Frequency Modulation on the UPIC System

Frequency modulation as a sound synthesis technique was first systematically investigated and developed by John Chowning [Chowning 1973]. FM is considered to be one of several mathematical techniques that falls under the broader class known as non-linear distortion or non-linear waveshaping. Such methods rely on non-linear mathematical functions for the synthesis of sound. In FM, two waveforms are utilized, one defined as the carrier, and the other the modulator. These terms are borrowed from the field of communications/broadcast engineering, as the technique has been widely used, for example, in the broadcasting of radio signals. The carrier waveform is used to "carry" the modulator waveform; the modulator waveform normally consists of the information signal that is to be broadcast over the airwaves (voice or music, for example). In the case of sound synthesis, the modulator waveform normally consists of a particular shape or form of a time pressure curve. Typically, the time pressure curve of the carrier and modulator waveforms follow a periodic or well-defined structure, such as a sinusoid or a triangle waveform, to name a few examples. The UPIC system, however, permits the user to specify any curve or shape for the modulator and carrier waveforms. Most often with the UPIC system, these waveforms are created by drawing the desired curves on the graphics screen with the pointer and mouse, or by the importation of a digitally sampled real-world acoustic signal into the computer. FM has found widespread popularity as a sound synthesis technique since it is capable producing timbres rich in harmonic content, from a minimum resource of two waveforms.

The implementation of FM on the UPIC system permits the user to remove the UPIC from its traditional mode of operation. Normally, once a graphical score has been entered on the UPIC page, the score is "read" by a cursor that traverses the page, registering the position of the arcs and translating these positions as time-frequency parameters which control the operation of the bank of digital oscillators in the sound synthesis unit. Recent work on the UPIC system utilizing the FM algorithms has shown that it is not necessary to organize arcs within the traditional UPIC model in order to create complex and interesting timbres. The user is not required to "represent" the sound or aspects of the sound's structure in the form of a drawing on the UPIC page. Instead, concentration may be placed on the organization of the FM algorithms themselves, as well as on the type of waveforms selected for the various arcs (Figure 1). The particular location of the arcs along the vertical axis (the frequency ambitus), coupled with the precise definition of the arc's horizontal position on the time axis (the specification of the phase relationships among the waveforms), combine to form an organizational structure enabling the cursor to now remain stationary on the page, fixed and free of any automated movement. It is the FM algorithm as defined by the composer that provides the synthesis of the sound. The composer may now choose to affect the resulting sound by adjusting various parameters of the algorithm in real-time, as the system generates the time-pressure curve information to the oscillator bank and then sends it to the loudspeakers.

The types of changes the composer may perform could include affecting the attenuation value of a particular modulator or carrier arc (the amount of intensity associated to the waveform), a reassignment or changing of a particular arc's waveform (a different wave type or sampled waveform may be assigned to an arc during the algorithm's operation), or the selection of a new group of arc-algorithms on the graphics page (the FM algorithm is now represented by the group of arcs on the graphics page, allowing the composer to organize a wide variety of these algorithms). Such real-time changes to the parameters of the algorithm renders the UPIC system a real-time computer music composition instrument.[3]

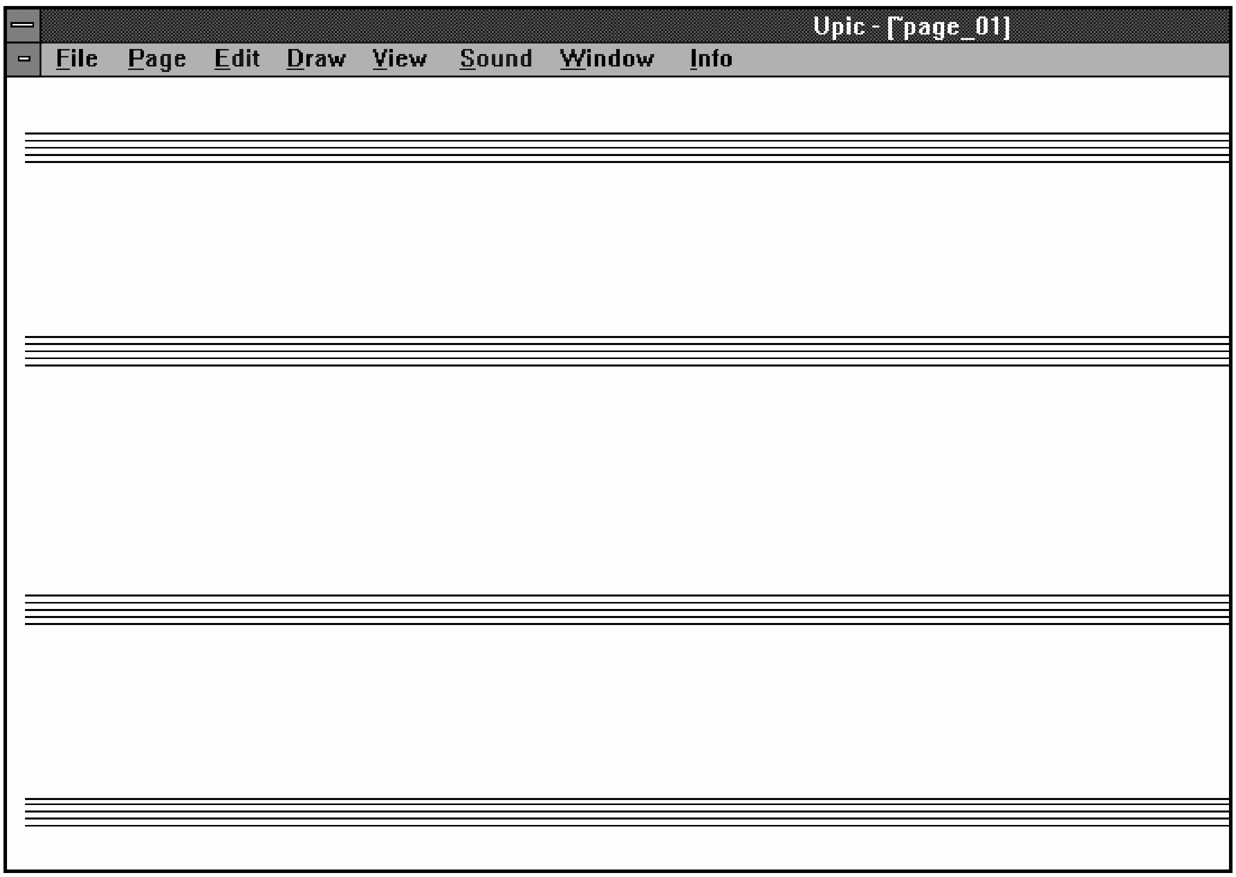

Figure 1 This figure shows a grouping of arcs from an UPIC graphics page created by the author for the performance of the composition *Maya*. These four groups are part of a larger set of arc groups (this is an enlargement of an area of the UPIC graphics page), which contains an additional six groups identical to the ones shown above, for a total of ten (the additional groups extend in a similar manner below the ones shown above). In addition, a smaller group of arcs, positioned lower on the graphics page (lower on the frequency scale), are used to frequency modulate the larger group. The larger group, in turn, modulates the second group, creating the recursive feedback FM synthesis algorithm.

[3] Xenakis had utilized the UPIC system in a live performance of his composition *Tauriphanie* in 1988 (composed in 1987) in Arles, France. "The UPIC equipment was placed beneath it [a wooden tower in the center of an amphitheater], inside the tower, so that I could improvise as the performance was going on" [Varga 1996, p. 193]. *Tauriphanie* was to be a "mixed" piece, for UPIC and the sound of live bulls. Xenakis performed the UPIC himself in real-time, but it should be noted that the manner in which Xenakis had applied the UPIC differs from that which is described in this paper. Xenakis had simulated the sound of the bulls, however, he had not implemented the micro-compositional techniques described herein.

How does this particular implementation of FM in the UPIC system at the micro-compositional level affect the resulting macrostructure of the sound? There appears to be a direct influence on and among several aspects of the sound simultaneously: namely the timbral, spatial, and temporal evolution of the sound as it is being synthesized by the UPIC system. The composition of the structure of the sound, its organization in time, develops during the operation of the algorithm and along with the interaction of the composer on that algorithm in real-time.

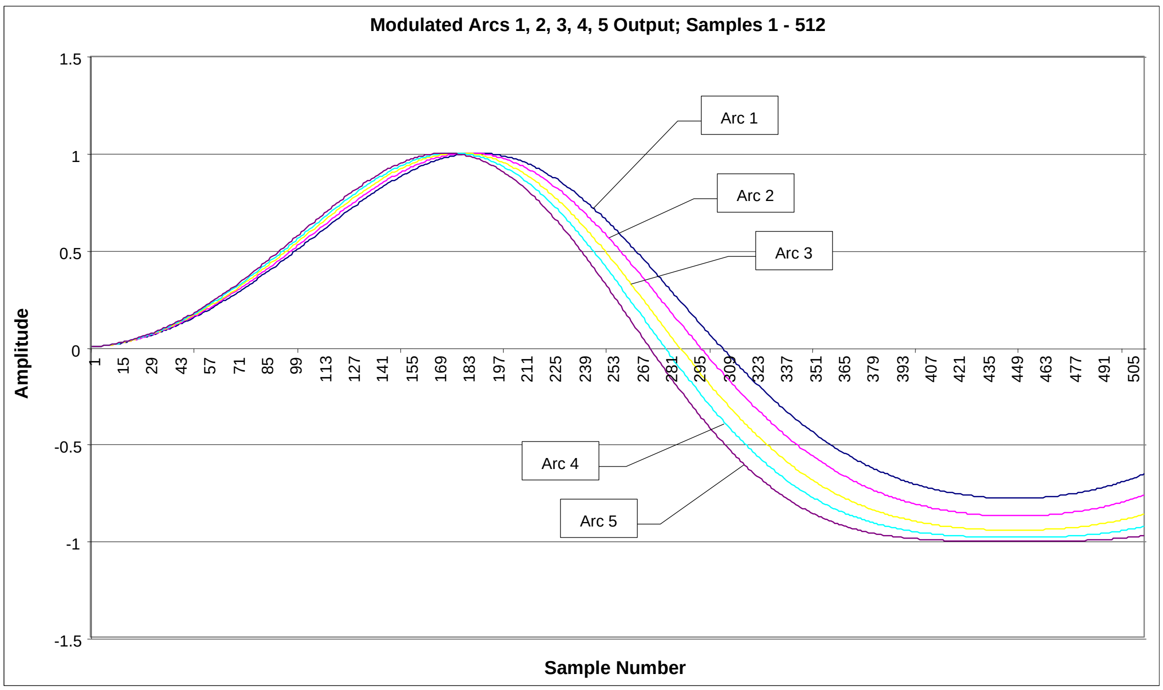

Figure 2 A graphic plot of the resulting time-pressure curves of five waveforms produced with the FM synthesis algorithm of the UPIC system as described in this paper. The five waveforms shown here correspond to the five lines (arcs) of a single group in Figure 1 (the oscillating frequencies in this case for arcs 1-5 range from 5.40-5.60 Hz). The difference in phase and amplitude can be seen among the various waveforms, as they develop over time. Although all the waveforms begin their time-pressure trajectory at time 0, the effect of frequency modulation on the five waveforms (each of which has slightly different oscillating frequency), produces a slight phase shift on the resulting sound, as well as a change in shape of the curve itself (which ultimately influences the timbre of the sound). These differences in phase directly influence the listener's perception of the spatiality of the sound in the air via the process of binaural hearing. The results shown in this plot are part of an UPIC simulation project by the author.

A Simulation of the UPIC System

We present here a brief analysis of the dependence of the resulting sound on the micro-level digital sample via a simulation of the UPIC system itself. This analysis is part of an ongoing project dedicated to obtaining a thorough understanding of the mechanisms involved in micro-compositional techniques as those utilized on the UPIC system and elsewhere. Such non-standard synthesis methods rely heavily on the precise specification of the digital sample within an amplitude-time-frequency space (digital synthesis of sound with a computer requires the representation of such sound as a "sample"). The organization of the digital sample in this amplitude-time-frequency space (and therefore the associated digitized waveforms used in the synthesis algorithms) bears a direct influence on the resulting macroscopic sound composition[4]. By bridging the amplitude-time-frequency space used to describe the sample, with the large-scale emergent listening space, we hope to present a means for more thoroughly understanding the inter-level relationships and processes present in such a micro-compositional approach to sound.

A New Temporal-Spatial Composition: Phase Yields Time, Space, and Timbre

In traditional sound spatialization techniques, the movement of sound is typically achieved through the use of complex panning techniques, where the audio signal is "pushed", "moved", or "routed" within the electronic circuits that comprise whatever external equipment is used to perform such signal manipulation (normally an elaborate mixing console often found in most studios). With the advent of computer techniques, the traditional model of space was retained, with the added benefit of delegating control of the sound to the high-speed number crunching capabilities of the computer. Instead of the composer having to turn knobs, press buttons, or push sliders, the computer could be programmed to direct the signal in an electronic circuit, and ultimately out of a pair of loudspeakers. Or, alternatively, carefully measured head-related transfer-functions (HRTFs) can be implemented in the form of digital filters: such digital filters are applied to digitized sound, resulting in the specific positioning of the sound in space. However, space, or spatial movement, is *added*, a-posteriori to the sound, after the sound has been created. Within the context of the UPIC system, or within the microstructure of the originating sonic material (in the form of the samples of the particular waveforms used in the FM algorithms), the concepts of space and timbre, or movement in the space of a timbre (sound), becomes and emergent aspect of the non-linear process used to create the digital samples in the computer. Timbre and spaciality are inextricably linked in the synthesis process. In other words, timbre and spatiality do not exist until the acoustic time pressure curves are created by the diaphragms of the loudspeakers.[5] The sound becomes the space, and the space is then defined by the sound, only through the interaction of the time-pressure curves and their complex interdependent relationships. External "panning knobs" are not required in order for sound to "move in space". What *is* required, within the UPIC framework (or, more specifically, within a micro-compositional framework), is the definition of specific phase relationships among the

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[4] Winckel makes an interesting observation regarding this fact. He states "The perception of a stationary room excited by an acoustical event occurs in the microstructure of the statistical reflections which reach the conscious through a process of integration." (*Music, Sound and Sensation: A Modern Exposition*, p. 78) Concerning the macrostructure of a sound on the listener, he continues "The 'whole' is a 'gestalt' in the sense of Gestalt psychology, it is perceived instantaneously, independent of time, just as thought…" (ibid.)

[5] Of course, our notion of space does not originate from a conception that is based on the internal architecture of electronic circuits or the particular designs of a loudspeaker enclosure. What we emphasize here is that the timbre and the spatiality of sound in the context of micro-composition does not rely on the established model of "moving" the represented sound with external equipment, be it a computer or other electronic device.

various waveforms in the FM algorithms.[6] In this case, the sound is not treated as a separate entity, dislocated from the actual process of composition (or listening, for that matter). The composer, in real-time, directly manipulates the samples, which comprise the waveform in the wavetables, while the algorithm is in process. The effects of such manipulations directly influence the macrostructure of the resulting sound. The physics of sound in the air, the physiological mechanisms in the listener, and the "black box machine" in the form of the general purpose computer coupled with a synthesizer, all form a dynamic, interactive listening environment where each element plays a role in the overall emergent development and impression of a sound on the listener. One might suggest that conventional composition ends with the score, micro-composition ends with the speaker membrane (in the context of spatial music), and "emergent composition" ends with the listener.

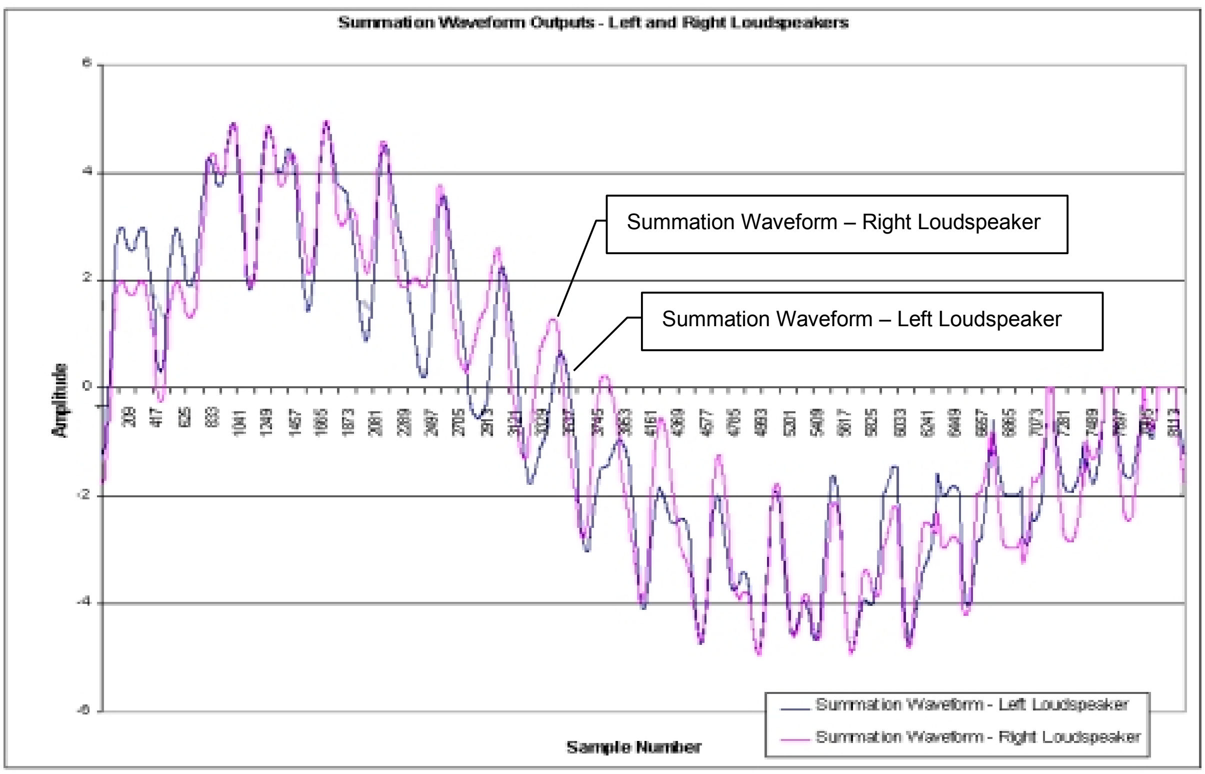

Figure 3 The resulting time-pressure curve as delivered by the loudspeakers, and received at the position of the listener's ears. These waveforms represent the summation of the individual synthesized curves, as generated by the FM algorithm, and shown in Figure 2. The difference in the shape of the two curves is due to the fact that the time-pressure curves, at the position of the listener's ears, will add together differently because of the delay caused by the interaural time difference (the distance between the listener's ears). Although the left loudspeaker delivers arcs 1, 3, and 5, and the right loudspeaker delivers arcs 2 and 4, all five time-pressure curves add constructively in the air. The interaural time difference, inherent in binaural hearing, contributes to the difference in timbre and directional cues detected by the listener.

[6] These phase relationships are an integral part of the phenomenon of binaural hearing. See [Winckel 1967] pp. 72-74.

Through the micro-structural specification and manipulation of the phase relationships among the various arcs (the digital oscillators) on the UPIC page, one has the ability to affect the emergent development of the temporal-spatial components of the sound in the air. Phase relationships between waveforms in the air are determined and specified by differences in units of time. These phase relationships may be defined within the UPIC system by the precise placement of the arcs on the page, where in some cases arcs may be placed to within one-hundredth of a hertz from each other[7]. Non-linear dynamic processes, as demonstrated by the FM algorithms possible with the UPIC, may in addition control these differences of phase. In the end, the air in the listening space is now not only a *transferal* medium, but also a *transformation* medium.

There appears to be a direct influence on several aspects of the sound simultaneously, namely the timbral, spatial and temporal evolution of the sound as it is being synthesized by the UPIC system. The composition of the structure of the sound, its organization in time, develops during the operation of the algorithm. The composition is not necessarily a priori to its existence. The algorithms are. The composer can become the performer of his immediate composition. This contrasts with the manner in which Xenakis had utilized the UPIC system in the past. In fact, the present UPIC system, when configured with the algorithms just described approaches Xenakis' ideas as implemented in his GENDYN[8] algorithm. The iterative feedback FM algorithm, coupled with the micro-compositional approach, permits the UPIC to be used as a pseudo automaton. Non-linear processes are used to create sonic structures in real-time.

Towards what direction can such microcompositional techniques lead us? We have seen that it is not necessarily a requirement to represent with the computer the sound itself in order to synthesize interesting timbres or structures of form. We must accurately represent the algorithm in the form of computer machine code. In addition, to achieve the sensation of spaciousness with the sound – movement and immersion – one is not obliged to "push" or "move" a representation of the sound within the electronic circuits of external equipment, or within the binary switching circuits of the computer itself: "panning knobs" or representations thereof are not necessary. Such aspects are emergent qualities of the algorithm, once the sound has been received by the listener. To extrapolate and pose a further question: can the sound be *synthesized in the air* itself? What we are suggesting in this case concerns the use of the computer (or any other peripheral equipment), not as a sound synthesis and delivery system, but as a tool that

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[7] It is interesting to note that related observations concerning the phase relationships among tones, and the ability to distinguish such tones, has been made some time ago, but from the point of view of the harmonic series and Fourier analysis. Henry Cowell, in *New Musical Resources*, discusses Leon Theremin's turn of the century electronic instrument, the Theremin, within such a context. The Theremin is capable of producing a tone at any frequency from within a continuous range, say Freq(low) through Freq(high), at potentially one-hundredth of a hertz resolution. Cowell states: "Another point to be observed grows out of the demonstrated fact that as overtones go higher and higher in the series, the tones comes closer and closer together.[…] Professor Leon Theremin, in a demonstration of his electrical instruments, showed that the interval of one-hundredth part of a whole step can be plainly discerned by an audience.[…] Theremin's instruments may make it possible to play the intervening and acoustically simpler intervals with as great ease as quarter-tones; thus, one of the main difficulties, that of performance, may be solved." - *New Musical Resources*, pp. 17-19, Cambridge University Press edition, 1996 (originally published by Alfred A. Knopf, Inc., 1930).

[8] GENerative DYNamics, [Xenakis 1992, Hoffmann 1996].

would affect the air (its molecular structure), directly, resulting in the possible formation of sonic volumes within the listening space. This would be a form of acoustic fluid synthesis, and the macroscopic sound composition would be the manifest emergent product of such an endeavor.

The spatiality of the resulting sound mass is but one of the characteristics affected by this micro-compositional approach to sound creation. Other aspects of the composition are also influenced simultaneously: timbre, form, gesture, and musicality itself. These have not been directly addressed in this paper. Our discussion has been directed towards the manner in which frequency modulation as implemented on the UPIC system can be utilized within the micro-compositional framework, and the ramifications of this process on the listening experience. We have shown that through careful and judicious adjustment of the digitized samples, during the execution of the synthesis algorithm, an emergent macroscopic composition results in its totality. The phrase "the whole is greater than the sum of the parts" can definitely be applied in this situation.

Xenakis' interest in the direct synthesis of the time-pressure curve led him from the initial implementation of the UPIC system where such curves were drawn and characterized by hand, to the implementation of the Gendyn algorithm, where the digital sample is created one-by-each, and where, as he describes, sound and music is generated from nothing, and set free through the use of stochastic functions. Both in the Gendyn algorithm, and in the current UPIC system, the composition itself becomes an emergent function of a process (algorithm) defined by the composer. Real-time systems now permit the composer to become performer of that composition, directly affecting the microstructure of the sound, in an immediate and direct way. Listening, reaction, and response can simultaneously become part of this interactive process. These tools [equipment(s)] of Xenakis could now take the form of musical composition instruments.

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