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COMPUTER MUSIC: WHY?

Introduction

One of my early desires as a musician was to sculpt and organize directly the sound material, so as to extend compositional control to the sonic level - to compose the sound itself, instead of merely composing with sounds. My use of the computer has focused mostly on this goal. I have been able to fullfill this desire to some extent by resorting to digital synthesis and also digital processing of sound. As I shall explain, I had to perform exploration and research to use the computer musically.

The computer: why and how?

My first pieces did not involve the electronic technology, and today I still compose works for the voice, the instruments and the orchestra: but I have spent much time exploring the possibilities of the computer for musical creation, mostly for the compositional elaboration of sound material. I had an early and vivid interest for timbre. However, in the early sixties, I was not attracted to either *musique concrète* - based on the editing of recorded sound objects - or *electronic music* - built up from electronically produced sound material. To put things simply, I found that although musique concrète was opening the scope of musical sounds, it did not provide to the composer with the refined compositional control he could exert when writing instrumental music. Musique concrète offers a rich variety of powerful sounds: however the possibilities of transforming those sounds are rudimentary in comparison, so that it is hard to avoid an aesthetics of collage. In contradistinction, one could control the sounds of electronic music more precisely, but these sounds tend to be so simple and dull that one is tempted to enrich them by complex manipulations, thus destroying the effectiveness of control one could have over them.

This conclusion prompted me to explore the possibilities of computer sound synthesis. I felt that the precision and the reproductibility of the computer could help - while I always found something limited, contrived and whimsical about analog electronics. Synthesis permits to "compose" sounds in great detail. The sound material thus obtained is highly ductile, and it can be made complex enough to be musically interesting, while too simple sounds can turn off demanding listeners.

Between 1964 and 1969, during several years spent with Max Mathews at Bell Laboratories, I devoted myself to the exploration of those possibilities. Then I went on, introducing computer synthesis in France - at Orsay (1970), Marseille-Luminy (1975), IRCAM (1976). I now continue to work in the Laboratoire de Mécanique et d'Acoustique of CNRS in Marseille, with Daniel Arfib.

Computer synthesis of sound: MUSIC V and the psychoacoustic problem

The most general method to produce sound is direct digital synthesis, implemented by Max Mathews as early as 1957 : the computer directly computes the numbers representing the waveform. Thanks to the flexibility of programming, it can thus produce virtually any waveform, without having to build an actual vibrating system.

To avoid rewriting a new program for each sound, Mathews has designed convenient music compilers such as MUSIC V, which enable the user to produce a wide variety of sounds, simple or complex. The user has to specify to the program the physical structure of the desired sounds. This specification - the computer "score" - must be made according to specific conventions, which in effect define a language for sound description. A given MUSIC V score is thus a recipe requested by the computer to cook up the sounds, and at the same time a thorough description of these sounds, which may be usefully communicated to other users.

One can thus manufacture sounds with unprecedented reproductibility and precision. This precision permits to achieve useful effects. Thus I have often taken advantage of the complex beating patterns between several similar synthetic tones with very close frequencies, using differences smaller than 1/10 Hz. Depending on the regularity of the spacing of the neighbouring frequencies, the interference between sounds yields conspicuous spectral scans, reinforcing in turn different frequencies at different rates (as in *Inharmonique*, 3'40s" to 4'28"[1], or *Contours*, 1'34" to 2'55" or 9'01" to 9'41") or simply animating the tone by modulating its color (as in the low pedal of *Songes*, track 1, 6'30" to 9').

However the first attempts to use direct digital synthesis for music were disappointing. The synthetic sounds produced in the late fifties and the early sixties lacked variety, richness and identity. One could not get exciting new sounds by varying parameters haphazardly.

Clearly, one lacked adequate physical descriptions of desired or interesting timbres. This is what we call the psychoacoustic problem: to use sound synthesis effectively, one must resort to some psychoacoustic knowledge or knowhow on the relation between the physical structure - which the composer controls when he specifies the synthesis data - and the aural effect -which determines the musical impact. "Classical" psychoacoustics is of little help here, since it bears mostly on the perception of simple sounds in isolation, while music deals with rich sounds in context. And the early synthesis attempts promptly revealed that auditory perception has intricate and apparently whimsical features.

Disseminating know-how: a catalog of synthesized sounds

Fortunately, the exploration of the musical possibilities of digital synthesis has contributed a lot to the growth of such psychoacoustic knowledge and knowhow. It is important to disseminate thi know-how. This can be done through scientific articles or books, specially

[1] The timing given in this article for musical excerpts is that of the compact disc recording of the piece referenced in the discography, with the track number if necessary: thus it is easy to find the proper spot.

accompanied with records (Risset & Mathews, 1969, Chowning, 1973, Mathews & Pierce, 1989).

After working several years to develop the possibilities of synthesis, I assembled "an introductory catalog of computer-synthesized sounds"(1969) to communicate the finds of my own research. In fact this compilation was requested by Max Mathews for a computer musi synthesis course he gave in 1969 with John Chowning at Stanford University. This document provides a recording for a number of sounds or musical fragments, together with the MUSIC V "scores" written to obtain them. These scores permit to replicate the synthesis - they also constitute a thorough description of the physical structure. Additional explanations are given on both the production process and the musical context. Thus the sounds can be replicated with MUSIC V, but also with other programs or other sound production processes. Most of the data I mention below on the imitation of instruments, the development of sonic processes or the creation of auditory paradoxes and illusions, can be found in the document in enough detail to replicate the examples today - or to produce variants from these examples. This document has proved useful.

This issue of passing information and know-how is crucial. A MUSIC V score (this also applies for scores of other synthesis programs such as CSOUND or CLM) gives complete information about the sounds and their elaboration. Analyzing scores is an essential part of teaching - or learning - composition. MUSIC V, CSOUND or CLM scores can be analyzed by composers interested in recipes for sound synthesis and in the compositional elaboration of sonic structures. Computer synthesis of sound would remain very primitive and unmusical if explorers had not shared the know-how they developed. Today, a considerable body of know-how is disseminated around C-Sound : Russell Pinkston of UT had contributed to this with his proposals about delay lines.

Today, Internet, as a world wide web, makes it easy to share resources: but theses resources must exit in the first place - not only the synthesis programs, but typical protocols of fruitful utilisation of these programs.

Back to psychoacoustics

In my talk on the perception of musical sound, I explain that hearing has developed as an idiosyncratic processes. The senses are not parameter-measuring devices: rather, perception has specific ways to interpret the sensory signals so as to get useful information about the outside world - the issue is survival. Hearing can thus make subtle inferences to interpret a sound signal in terms of its acoustic production: however it is often at a loss with electrical sound signals which escape acoustic constrainsts (Cf. Risset, 1988, Bregman, 1990). To identify a source, the ear relies on subtle and more elaborate cues than one thought, such that the identification can resist the distorsions happening in the course of the propagation of the sound signal.

Even familiar sounds, such as those of musical instruments, were harder to imitate than expected. In particular, brass and bowed string instruments fiercely resisted imitative synthesis. Evidently, the cues for the recognition of these instruments were not as simple as one thought. Thus, in the early sixties, Mathews and I decided to embark on some research on imitating those sounds - not to provide ersatz, but rather to get insight on what determines the richness and the identity of violin or trumpet sounds.

Early experiments: imitation of instruments and its musical use

The methodology we used can be called *analysis by synthesis*. The classical desciptions of instrumental sounds model them in terms of a characteristic fixed spectrum modulated by an amplitude envelope. The initial attempts to imitate brasses or strings with such a model failed completely, showing that the model is inadequate. In fact, using this model, electronic music had not succeeded in the fifties to properly imitate instrumental sounds.

We analysed recorded tones, using protocols yielding the evolution of frequency spectra over time rather than a single, average spectrum. The time-varying analysis of trumpet sounds showed that the spectrum was variable throughout each tone. In particular, during the attack, the low-order harmonics reached their final amplitude earlier than the high-order ones. On hearing the attack, the ear cannot analyze what happens, it is not aware of this asynchrony, which occurs over some 30 milliseconds: but it recognizes it as a characteristic cue of a brassy attack, as synthesis tests demonstrate. Indeed, good simulations of the original tones could be achieved by modeling the sounds as a sum of harmonics, each of which endowed with its own envelope. The complex envelopes drawn from the analysis of actual brass sounds can be vastly simplified: however, a considerable amount of data is still required - especially since a new set of envelopes is required for tones of different pitches or different loudnesses. Clearly, it is valuable to try to characterize the timbre in a more compact way. I found that brassy tones could be characterized by a rather simple property: the higher the amplitude, the richer the spectrum in high order harmonics. In particular, this ensures the asynchrony of the harmonics during the attack. This insight permitted me to synthesize brassy tones "by rule", the amplitude of each harmonic being deduced automatically from the envelope for the first harmonic, as shown in example 210 of my Sound Catalog (1969).

I have dwelt at length with the case of my analysis by synthesis of brassy tones because it had several implications. It made it possible to produce brassy sounds with analog synthesizers: the property can be implemented thanks to filters with voltage-controlled bandwidth. But the most elegant implementation came later with John Chowning's frequency modulation: the modulation index, which determines the frequency bandwidth, can be made to follow the envelope. Chowning has indicated that the property characterizing the brassy tones helped him realize the potential of his FM process - audio frequency modulation. FM has been used extensively in computer software sound synthesis, but also in digital synthesizers such as the Yamaha DX7 and in the New England Digital Synclavier.
Synthesis experiments also show the importance of a wealth of specific details, sonic "accidents" or idiosyncrasies helping the ear to identify the origin of the sound. Even tuning characteristics can also affect what is called "timbre".

Imitations of percussion instruments sound "synthetic" unless the decay times is different for different components - in general, longer for lower frequencies. This is demonstrated by n° 430 of my Sound Catalog.

I did not, however, initially intend to use the computer for imitation purposes. I am not interested in replacing acoustic instruments by bad copies, and I find that instrument-like synthesizers sound most of the time as degraded ersatz. However there are some good reasons to use instrument-like synthetic sounds. The palette of the computer would not be complete if it did not include those sounds which are very familiar, and which have proven their musical utility. In fact, the strong identity of instrumental timbres can be an anchor, a point of departure for journeys throughout timbre space. In *Little Boy* (track 6, 0" to 1'), one can hear simulacra of various instruments: brass, piano, drums that get frantic and turn into bursts of gun-fire. The ductility of synthesis permits to perform transitions between two timbres - intertwinning or morphing, as one says in the visual domain, rather than mere merging; freezing textures or melting objects, as decribed below for the tape of *Inharmonique* .

Instrument-like synthetic sounds can also be contrived as acoustic sounds could not be. Bells and gongs have inharmonic spectra upon which the composer has no fine control: he can however compose synthetic bells and gongs with a prescribed harmony, thus relating harmony and timbre, as I often do (Cf. *Mutations*, 0" to 8", or *Dialogues*, 6'21").

Compositional development of textures

In the previous example, timbre becomes functional: it constitutes the musical material, but its specific intimate structure relates to harmony, it has implications over the syntax. A synthesis program like MUSIC V permits to control both the synthesis of sounds and their disposition: the user can thus merge vocabulary and syntax. I have used additive synthesis to produce complex sounds by adding synchronous components, harmonic or inharmonic, but also to desynchronize such components - to produce, for instance, an arpeggio by shifting the successive components in time. Depending upon their harmonic relation and their behavior in time, the components can merge into a single sound entity or be perceived as a multiplicity of sounds. For instance, in , one can hear arpeggioes of harmonics which emanate from pitches of a chord. I call this *spectral analysis of a chord* : it is as though the harmonics of the notes of the chord were selected through a frequency window moving from the high to the low frequencies

The title of my piece *Mutations* (1969) refers to the form of the piece, mutating from discontinuous into continuous, but also to the mutation stops of the organ: the harmonics, shifted in time similarly to components of white light dispersed by a prism (29 " to 35", 36" to 52", 1'06" to 1'17", 1'56" to 1'58", 2'06"), as though one admitted air in turn into the distinct pipes which are normally mixed to make up a tone. Between 1'41" and 1'47", one can hear a sustained chord undergoing a collapsus of timbre, as though all pipes above the fundamental were gradually muffled.

One can hear such "spectral analysis" or "spectral emanation" from a chord or a harmonic structure in several pieces - for instance in *Little Boy* (1968) (track 4, 0" to 26", also 2'25"; track 5, 1'25" to 1'35"; track6, 1'17" to 1'24", also 3'47" to 4'15"); in the tape part of *Inharmonique*, 4'59" to 6'08"; in *Contours* (1983), 6'29" to 7'13", 7'28" to 8'20", 2'47" to

4'50". In the latter example, the various harmonics of the components of seminal chords such as C,D,G#, A#, E, F#, are presented in melodic-harmonic patterns which are not simple arpeggioes, but two-dimensional structures controlled in a quasi-graphical way.

In *Inharmonique* (1977), one can hear what seems like a set of bells - synthetic bells which I composed like chords, adding components of different frequencies, with a decaying amplitude envelope longer for lower pitch components. The synchronous attack helps the ear fuse the components into a single sound entity - a "bell" (6'32" to 8'05"). Later on(9'14" to 10'), I reproduce the same passage, but with an envelope of a different shape to control the "bell" components This change of envelope turns the percussive bells into fluid sound textures. The maxima of the envelope are no longer synchronous, which helps the listener to separate out the components and to hear, so to say, the interior of the sound. This separation is even easier later between 10'05" and 11'35", with an envelope that bounces. Here the control of the additive synthesis envelopes permits the composer to transform the sound in ways akin to changes of physical state - freezing or melting a given substance (the harmonic components remain the same). Such changes can also be heard, for instance, in *Passages* (on track 3, liquid between 1'16" and 3'16", solid between 3'23" and 3'55"). Recently I ported the synthesis of such inharmonic tones to the real-time program MaxMSP, with the help of Antonio Sousa Dias and Daniel Arfib : I used this for the last movement of my piece *Resonant Sound Spaces* (2002).

One can see from the above examples my concern about the harmonic structuring of timbre. In my view, grammatical constrainsts such as the serial techniques are too arbitrary in the harmonic dimension. With synthesis, one can compose spectras and timbres just as musical chords, and one can attribute a harmonic function to timbre. There is a relation between the inner structure of an inharmonic tone and the privileged frequency intervals between transpositions of such tones: the octave, the fifth and the third are privileged for harmonic tones with component frequencies f, 2f, 3f, etc, but they can be highly dissonant intervals for certain inharmonic tones. In *Little Boy* (track 6, 2'27" to 3'18"), *Mutations* (5'19" to 5'40", 6'22" to 6'37") and *Songes* (5'35" to 6'40"), I have thus piled up inharmonic textures as nested structures, chords of chords: the frequency ratios between the transposition are the same that can be found beeen the components.

Auditory illusions and paradoxes

By exploiting the specific idiosyncrasies of hearing, one can produce auditory illusions. Visual illusions are well known, while auditory illusions are recent. This is because one can draw a contived figure with a pencil: but before computer synthesis, one could not contrive the structure of a sound in a similar way.

I have been interested in paradoxes and illusions to create musical, morphological or theatrical effects - but also because illusions reveal the very stuff of our hearing, as I discuss in my talk on the perception of musical sound.

With inharmonic sounds, the listener is likely to experience pitch relations which do not correspond to the frequency relations prescribed by the composer. This can happen for a great proportion of inharmonic tones.

I have generalized Roger Shepard's *chromatic scale to heaven*, generating endlessly descending or ascending glissandi for *Little Boy* (track 5, 0" to 2'50") and *Mutations* (5'40" to 6'21", 6'35" to 7'30"). Later, I implemented an instrumental rendition of such endless scales in the choral piece *Dérives* (1985) (movement III) and in the third movement of *Phases* for orchestra (1988), in *Triptyque* for clarinet and orchestra (Cf. Braus, 1995) and in *Escalas* for orchestra (2001).

In *Little Boy (*track 6, 2'17" to 2'25"), *Mutations* (7'31" to 7'39"), *Moments newtoniens* (track 9, 1'17" to 1'36"), one can hear a sound which goes up the scale yet which is lower in pitch at the end than where it started (or vice-versa). This is the auditory counterpart of Escher's *Cascade*, where a stream appears to flow down ... to a higher point. Here I contrive the parameters so as to give rise to a conflict between two aspects of pitch - tonal pitch and spectral pitch. The trick is to gradually increase the amplitude of the lower components to the prejudice of the higher ones while all components are going up in frequency: the center of gravity of the spectrum moves in a direction contrary to the movements of the components.

The MUSIC V score can be found in my 1969 Catalog, # 514. The brevity of the score shows that even very peculiar sound structures, where sounds are contrived in a most unnatural way, can be specified rather simply.

In *Moments newtoniens III*, the previous pitch paradox is combined with a similar rhythm paradox: a beat that speeds up constantly, yet it is slower at the end than at the beginning (track 9, 1'42" to 2'18"). This is followed by the reverse, a slowing beat which eventually gets much faster (track 9, 2'23" to 3'00"). Similar pitch and rhythm paradoxes can be heard in *Mirages*, for chamber ensemble and tape (1978) and in *Electron-Positron*, a short 8-track piece commissioned by CERN for the inauguration of LEP, the large electron-positron collider: the pitch and rhythm paradoxes alludes to the rotation and the acceleration of the particles.

Intimate transformations of digitized sound

Synthesized sonic material is higly ductile and susceptible of intimate transformations. However it can be dull, "dead and embalmed", as Varèse said, unless one takes care to animate sounds, to inject life into them. Instead of doing synthesis, one can take advantage of live sounds and process them by computer to tailor them to compositional needs. My piece *Sud* gradually merges natural and synthetic sounds.

However one should be aware that it is not easy to transform natural sounds with the flexibility and the ductility available in synthesis. For instance a frequency transposition of a recorded motive will also change the tempo of the motive and move the spectra of the sounds.

Advanced techniques of signal processing can now be used to perform intimate transformations upon recorded sounds. These techniques implement a so-called *analysis-*

synthesis process: they decompose the signal into elements that can then be assembled together to reconstitute the original sound. Between analysis and synthesis, the data can be modified so as to transform the sound. For instance, if the analysis permits to separate parameters corresponding to an excitation and a response, these parameters can be modified independently. One can then change the speed of articulation of a recorded spoken voice by a large factor without altering the timbre or the intelligibility. This has been demonstrated using several signal processing techniques such as linear predictive coding or phase vocoder. Such techniques also allow to produce sound "hybrids" via cross-synthesis: from two sounds, cross-synthesis creates a final sound which retains certain characteristics of both sounds. For instance one sound can imprint its frequency content and the other its dynamic contour over the final sound (Cf. de Poli & al., 1991). I have made musical uses of these techniques in pieces discussed below: *Sud, Voilements, Invisible.*

About some tape pieces

I shall give some details about non real-time compositions "for tape". They resort to processes described above.

Most of *Songes* (1979) was synthesized by computer at IRCAM: however, at the beginning, a virtual chamber ensemble can be heard. It is made up of short fragments recorded separately by different instrumentalists and subsequently modified and mixed with the Music V program. The scenario of the piece imply a progression toward a more and more oniric character. Thus instrument-like tones are recalled occasionnally by trills moving in space; bell-like percussions are dissolved into fluid textures; and the tessitura, initially centered in the medium range, gradually expands to a climax with a wide frequency span, followed by a coda comprising only undulating high tones which fly above a low pedal.

Sud (1985) uses both synthesized sound materials and recorded sounds, mostly sounds recorded near Marseille and subsequently submitted to a number of successive transformations through digital processing at INA-GRM in Paris. The piece gradually merges these two kind of material, initially presented as distinct and separate. A major-minor scale is initially present in the synthetic sounds, while most natural sounds have no distinct pitches (for instance the sounds from the sea) or pitches over which the composer has no control (the sounds from birds or insects). However the two worlds are made to merge gradually, thanks to the imposed transformations. Thus, for instance, the scale is gradually imprinted as a grid onto sea or bird sounds by means of resonant filters tuned to the steps of the scale; the frequencies of the insect sounds are transposed to those of the scale. Conversely synthetic sounds are given the dynamic profile of natural sounds such as sea waves. This is done by means of cross-synthesis, which merges two sounds into an hybrid, in a way reminding of Paul Cézanne, who wanted to unite "curves of women with shoulders of hills". I selected a found sonic object - the ebb and webb of a wave on rough sand which I recorded one morning - as a seminal cell, used throughout the piece at different scales, from that of individual sounds onto which the flux of this object is imprinted, to that of the general form, influenced by the idea of the wave.

Invisible (1996), for soprano and tape, will be sung in Austin by Larisa Montanaro. The voice of Irene Jarsky is heard in the tape of the piece. Other sounds have been obtained by synthesis or processing. One can thus hear illusory voices synthesized with the Music V program, harmonically composed timbres produced with Music V or with the real-time Syter audio-processor, voices transformed in various ways - time-stretching without frequency transposition, almost freezing the course of time, harmonizations, hybrids of voice and wind sounds, obtained with the Sound Mutations program, which implements the Gabor and the wavelet transform.

Resonant Sound Spaces (Espaces résonants) is a spatialized version of *Resonant Soundscapes (Paysages résonants)*, a work commissioned in 2001 by the city of Basel and dedicated to Gerald Bennett. The 8-track spatialization has been realized in 2002 at Groupe de Musique Expérimentale de Marseille (GMEM) thanks to the spatialization software *Holophon* by Laurent Pottier. The work was not intended as a systematic study of the phenomenon of resonance, but the sound material calls mostly for resonant tones, both synthesized, recorded and processed : percussions and plucked strings (free vibrations of excited solids), brasses and horns (forced vibrations of air masses), resonant filtering, reverberation. The adjective *resonant* also serves as a metaphor. It refers to one's strong reaction to certain sounds or sound sequences, in particular to the symbolic connotations of their apparent origin - even though this origins may be illusory. The piece evokes or quotes sonic elements to which I strongly resonate : the bell tone at the onset of Varèse's *Poème électronique*, motives sung or performed by Irène Jarsky, Denise Mégevand, Michel Portal and Serge Conte, bell concerts organized by Llorenc Barber, tones from the percussion instrumentarium of Thierry Miroglio.

The spatialization turning *soundscapes* into *sound spaces* has been effected from the multiple tracks of the Pro Tools sessions, that is, starting from multiple sound sources before their stereophonic mixing. The spatial dissemination of sounds enhances depth is the litteral sense, but also in the figured sense : it helps hearing to sort out the multiplicity of sound sources, thus facilitating for the listener a personal exploration of the proposed sonic territory. But it also proposes specific spatial figures;

The work comprises five sections - five different *soundscapes* - the title of which refer to the material or the process used (Bell-metals, Filters ...). However these may be illusory or "virtual" - for instance, all the "bells" of the second part of section V (except one) have been synthesized : no metal, no percussion.

Associating acoustic and digital sound: *pièces mixtes*

It is of interest to me to stage close encounters between the *real* world of instrumental sounds and the *virtual* world of synthetic sounds: these worlds can merge closely as well as diverge widely. I have thus realized a number of *pièces mixtes* associating digital sound - synthetic, processed, or both - with live instruments (from 1 to 16) or with the human voice. In nearly all of these pieces, the digital sound part was realized in advance, so that one can speak of pieces for instruments (or voice) and tape. I found this preferable: mixed pieces like

Dialogues (1975) or *Inharmonique* (1977) are still played today, while most the real-time equipment of that time is no longer available[2].

Dialogues (1975) combines four instruments - flute, clarinet, piano, percussion - with a tape synthesized with Music V in Marseille. The composition is based on a nucleus of motives forming pitch and rhythm rows. The treatment of the motives by compositional programs gradually dissolves the rows and submerge them into residual harmonies. The piece attemps to bridge the worlds of instrumental and synthetic sound. The instruments and the tape carry on dialogues: they answer each other, clash with each other, extend each other or merge with each other. Thus, in the beginning, the flute and the clarinet stealthily emerge from the tape sounds; at one point the tape provokes the percussionist to react to its suggestions. Toward the end, the tape weaves and frays sound structures stemming from instrumental harmonies.

Inharmonique stresses the theatrical aspect of the confrontation between a live soprano on stage and synthetic sounds with no material counterpart. The tape was entirely synthesized at IRCAM, except for a projection of the soprano's voice into space toward the end. The piece begins by shifting noise bands, out of which pure sounds emerge. These sounds cluster into clouds. The density increases. The voice, initially in the background, pierces the screen of the artificial sounds, and embroiders around a single pitch. The tape introduces imaginary bells, composed like chords, and later melted into fluid textures. The voice part becomes more and more sparse and dramatic, until only breathing remains, soon drowned into the reflux of noisy bands. The symbolics is one of emergence, birth, growth, death and memory. In *L'autre face*, on a poem by Roger Kowalski, the theatrical confrontation is even stronger, when the voice of the soprano is echoed by intriguing, disincarnate voice-like synthetic melodies.

In *Voilements*, the saxophone dialogues with a tape. Most of the tape sounds have not been synthesized, but rather obtained by processing of recorded musical motives played by saxophone player Daniel Kientzy prior to the realization of the tape, and including special performance techniques developed by the performer (multiphonics, slap, bull's sound ...). Although much of this processing was performed on a real-time system - the audio-processor Syter - I decided that the saxophone should be accompanied by a tape rather than by Syter operating in real-time on the concert stage. The reasons are several: convenience - it is costly to have Syter on the concert stage; fear of obsolescence - it is more and more difficult to maintain Syter, technically obsolete today; desire of richness - in places, the tape has more layers of sound than could be produced in real-time by the processor. The tape also includes sounds synthesized by Music V, but specified in real time through a MIDI keyboard - the pitches and timing were then transcribed to form the Music V score. However MIDI note 60 was not alway used as equally-tempered middle C (as it is in track 7, 2'43" or 3'01"): the MIDI note numbers could also be transcribed into steps of a non-tempered scales (for instance at track 8, 1'15" to 1'38").

In the course of *Voilements*, the tape first echoes the soloit, multiplying his sound, but also altering its way of playing, warping it as a wheel which does not go round (the title alludes to a veil or a sail, but it also means "buckles" or "warps"). The equal temperament tuning is eroded by microtonal intervals or multiphonics; the tension increases, up to a point where melodic lines get twisted into loops as on a broken record. Then, as if one zoomed backwards, the relation between the soloist and the tape become more remote and peaceful: the tape becomes a distant background for the gestures of the soloist.

Real-time performance interaction in the acoustic domain with a computer-controlled piano

In the 80s, Barry Vercoe, working initially with Larry Beauregard at IRCAM, then in M.I.T., has implemented a process whereby a computer program followed the score played by a performer, so that a *synthetic performer* can accompany the live performer. This was used in pieces by Philippe Manoury, such as *Jupiter*, for flute and 4X.

As as I was composer in residence in the Music and Cognition Group, Media Laboratory, M.I.T., I realized in 1989 a *duet for one pianist* which is is the first example of real-time interaction in a purely acoustic world. In addition to the pianist's part, a second part is played on the same piano - an acoustic piano, with keys, strings and hammers - by a computer which follows the pianist's performance. This requires a special piano - here a Yamaha Disklavier - equipped with MIDI input and output. On this piano, each key can be played from the keyboard, but it can also be activated by electrical signals: these signals trigger motors which actually depress or release the keys. Each key also sends out information as to when and how loud it is played. The information to and from the piano is in the MIDI format, used for synthesizers. A Macintosh computer receives this information and sends back the appropriate signals to trigger the piano playing: the programming determines in what way the computer part depends upon what the pianist plays. This novel interaction was implemented with the most dedicated and competent help of Scott Van Duyne. We used the real-time program MAX written by Miller Puckette at M.I.T. and at IRCAM.

My first *duet for one pianist* comprised short *sketches* or *etudes*, intended to explore and demonstrate different kinds of live interaction between the pianist and the computer. The scores for these pieces are fully written in advance, and so are the programs which determine the relationship between what the pianist plays and what the computer plays. The computer programs detect certain events in the MIDI sequence and take them in account in various ways to react in the desired fashion. In each piece a different kind of interaction is implemented.

Clearly, this process can merge composition and performance: compositional rules can be programmed and made sensitive to the way the piano is played. For instance, the tempo or the harmony of the added part could be determined by the loudness of the performance. Athough the process lends itself very well to improvisation, I have not used it myself in this context. I continue this work in Marseille, where I realize *Etudes* resorting to similar kinds of interaction.

Conclusion

Rather than specializing, for instance, in electroacoustic music or instrumental music, rather than being merely a composer without intervening in the performance aspects, I long for a complete approach. The computer is useful as a workshop to design and build tools which are material as well as intellectual. Using the computer has helped me to bridge gaps between various aspects of music making. I could thus relate acoustic and synthetic sound material; real-time and delayed synthesis; synthesis and processing of sound; music composition, sound production and performance. I only briefly touched upon form, which I often treat as a result rather than as a pattern *a priori*. In my pieces, I attempt to relate form to the material and its treatment - drifting forms, when the material evolves throughout the pieces, as in *Mutations*, *Songes* or *Voilements*, or forms influenced at different levels by a basic sonic kernel or a morphogenetic idea, as in *Sud*, *Attracteurs étranges* and *Invisibles*.

The computer has helped me reach certain aesthetic goals, to fullfill some yearnings which I may describe as follow: resorting to a large vocabulary of sounds, including and going beyond those of musical instruments; sculpting and composing sounds, with due regard to the harmonic dimension; stimulate perceptual mechanisms to produce auditory paradoxes and illusions; staging close encounters between acoustic sounds, audible traces of a visible world, and immaterial sounds, suggesting an imagined, illusory world, a separate, internal sonic reality.

Some references on my works and the issue of computers and musical aesthetics

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- http://ccat.sas.upenn.edu/music/music55/sept16.html
- An application to walk along the chroma circle
http://www.exploratorium.edu/exhibits/highest_note/fr.discrete.html
- Endless scale (Shepard) and endless glissando (Risset)
http://asa.aip.org/sound.html

Discography of works by Jean-Claude Risset

Vinyl records

- Computer Suite from Little Boy. In Voice of the Computer (avec Tenney, Lewin, Pierce, Mathews, Slawson), Decca 710180.
- Mutations. Winners of the Dartmouth International Electronic Music Competition (avec Asuar, etc.).
- Mutations, Dialogues, Inharmonique, Momens newtoniens. INA-GRM AM 564 09. Label MFA (Musique Française d'Aujourd'hui).
- Inharmonic Soundscapes (avec Petersen, Dashow, Wessel, Olive, Thome, Ghent, McKee). New Directions in Music, Tulsa.
- Songes (extrait). In L'IRCAM: un portrait (1980).

Compact disks

1. Songes, Passages (Pierre-Yves Artaud, flûte), Little Boy, Sud. C.D. WERGO 2013-50 (distrib. Harmonia Mundi).
2. Sud, Dialogues, Inharmonique, Mutations. C.D. INA C 1003 (distrib. Adda).
3. Contours. C.D. NEUMA New Music Series vol. 1, 450-71 (avec Xenakis, Scelsi, Korde, Lippe, etc) (distribution Harmonia Mundi).
4. L'autre face (Irène Jarsky, soprano). C.D. Wergo 2027-2" Computer Music Currents" n° 7 (avec Bodin, Yuasa, etc) (distribution Harmonia Mundi).
5. L'autre face (Maria Tegzes, soprano). C.D. Neuma Electro Acoustic Music 1, 450-73 (avec Lansky, Dodge, Saariaho...) (distribution Harmonia Mundi).
6. Voilements (Daniel Kientzy, saxophone ténor) . C.D. "Sax-Computers" (avec Racot, Teruggi), INA-GRM C2000 (distribution Adda).
7. Rounds (Michel Oudar, piano). C.D. Copsi-Empreinte digitale 13007 (avec Scriabine, Boeuf, Diennet, Berio) (distribution Adda).
8. Echo for John Pierce. C.D. ICMA/ICMC'92 (PRCD1300) (avec Kimura, Harrison, Degazio ...).
9. Moment newtonien n° 3. Choisi pour illustrer le disque compact "Mille et un poèmes - Poèmes français du XXe siècle (Planète vol. 1, Compacts Radio-France 1988).
10. Huit esquisses en duo pour un pianiste. Enregistré par l'auteur au M.I.T. C.D. Neuma 450-87, Electroacoustic Music III (avec Saariaho, Karpen, Nelson, Dusman, Fuller)) (distribution Harmonia Mundi).
11. Invisible (Irène Jarsky, soprano). C.D. GMEM/Effect Input EI 06.
12. Triptyque pour clarinette et orchestre (Michel Lethiec, clarinette, Orchestre de Cannes Provence Alpes Côte d'Azur, dir. Philippe Bender). Avec Berio, Bernstein. Sonpact SPT 97020.
13. Mixte (Marie-Cécile Cuniot, flûte). Double C.D. de la Société Internationale de Musique Contemporaine (avec Koechlin, Dutilleux, etc).
14. Saxtractor (Daniel Kientzy, saxophone). C.D. Neuma (avec Saariaho, di Scipio ...)
15. Huit esquisses en duo pour un pianiste. Enregistrement par J.C. Risset sur le disque compact CD Digital Rewind 25, Media Lab, MIT Experimental Music Studio (avec Child, Roads, Vercoe, Harvey, Davidovsky ...)
16. Attracteurs étranges (Serge Conte, clarinette), Invisible (Irène Jarsky, soprano). CD Prix Magisterium, Bourges 1998, Cultures électroniques 11, IMEB/UNESCO/CIME (avec Kotonski).

17. Extrait de Mutations, in The Early Gurus of Electronic Music, Ohm/Ellipsis Art, CD3670 (avec Babbitt, Bayle, Cage, Chowning, Reich, Schaeffer, Stockhausen, Varèse, Xenakis ...)
18. Extrait de Mutations, in 50 ans de musique électroacoustique au Groupe de Recherches Musicales, Teatro Massimo de Palerme, CD F.T.M.002A-B (avec Amy, Ballif, Bayle, Carson, Dufour, Dhomont, Ferrari, Henry, Lejeune, Leroux, Mâche, Malec, Parmegiani, Parmerud, Redolfi, Reibel, Schaeffer, Smalley, Stockhausen, Teruggi, Varèse, Xenakis, Zanesi...)
19. Saxatile (Daniel Kientzy, saxo soprano). CD en hommage à Xenakis : CCMIX Paris : Xenakis/UPIC/Continuum, C.D. Mode, New York 2001, distribution Abeille (avec Xenakis, Mâche, Estrada, Pape, Shimazu, Teruggi).
20. Avel, Luraï, Trois études en duo, Invisible Irène, Elementa (Denise Mégevand, harpe celtique, Irène Jarsky, soprano, Jean-Claude Risset, piano). CD INA-GRM C 1019 "Elementa".
21. Mokee (version soprano : Rovena Koreta, soprano, Rudina Ciko, piano), CD GMEM "Mélodies, de Tirana à Marseille" (avec Boeuf, Clot, Kushta, Dergjini, Peçi).
22. Voilements (Fabien Chouraki, saxophone). CD Paysaginaire, Visages du Saxophone n°5, 871106-SC 871, distribué par Socadisc (avec Veldhuis, Lejeuene, Dhermy, Rolin, Cavanna, Becker).
23. Passages (Roberto Fabbriciani, flûte). In the 2 CD album, Flute XX (Maderna, Risset, Clementi, Donatoni ...), Arts 47702-2 (Fabbriciani, flûte).

N.B. These CD can be ordered from the Electronic Music Foundation, http://www.CDeMUSIC.org. Some can be obtained in certain stores such as Tower Records, Amoeba (Berkeley). Some (C.D. n° 2 , 6 and 20 in particular)can be ordered at Metamkine, 13 rue de la Drague, 38000 Fontaine, France, tél. (33) 04 76 26 04 84, FAX (33) 04 76 53 07 13, which diffuses electroacoustic music. INA CDs can be ordered from INA-GRM, room 3521, Maison de Radio France, 116 avenue du Président Kennedy, 75220 Paris cedex 16.