Examples of the musical use of digital audio effects

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Abstract

This tutorial gives examples of the musical use of digital audio effects, drawn mostly from my computer music pieces *Sud* and *Invisible*. Rather than on the technical implementation, the emphasis will be placed upon the musical purpose of the effects, called for in order to simulate large spaces and illusory source movements; to create transposed echoes or choruses; to stretch words and sentences in time; to imprint selected pitches or harmonies onto sounds of natural origin.

1 Introduction

I would like to give here a few examples of the use of digital audio effects in my computer music pieces. The effects used include mixing with delays and transpositions, reverberation, 3D-sound, use of tuned resonant filters, time-frequency scaling, cross-synthesis. Rather than on the technical implementation, I shall emphasize the musical purpose of the effects. Thus these effects will not be presented in any systematic order.

2 Simple time-domain processing (*Inharmonique, Songes*)

In many of my computer music works, and specially the earliest ones (*Little Boy, Mutations, Dialogues, Passages, Contours)*, I have used sound synthesis only. However I began to introduce some computer-processed sounds in pieces such as *Inharmonique, Songes, L'autre face*. In these pieces, I only used fairly simple processing, mostly confined in the time domain.

In *Inharmonique*, a piece for soprano and computer-generated tape, realized in 1977 at IRCAM, I generated the tape entirely with the MUSICV sound synthesis program : most of the sounds are synthetic. However I recorded a melodic fragment sung by soprano Irène Jarsky, and I processed it with MUSICV to spatialize it. MUSICV was originally designed by Max Mathews so as to be able to perform processing of digitized sounds as well as synthesis, but a special unit generator had to be added by John Gardner to actually input the sound from a sound file into the program. The sound file could be read with increments different from unity, which yields sound transposition. In *Inharmonique*, no transposition was used, only a mere echo-like mixing of the recorded melody to itself (this can be heard between 13mn42s and 13mn54s on track # 5 on the INA C1003 recording). This gives the impression that the voice spreads into space.

In *Songes*, realized at IRCAM in 1979, I recorded simple melodic motives played separately by soloists of the Ensemble Intercontemporain (violin, viola, cello, flute, oboe, clarinet, horn, harp). I transposed some recordings by two semi-tones. I used MUSICV as a (non real-time) mixing program, so that the beginning of the piece sounds as a chamber ensemble - an illusory one, insofar as the performers never actually played together (this can be heard on track 1 of the Wergo 2013-50 CD recording, between 0 and 37s and between 48s and 1mn28s). I also used later in the piece some "spatialized" trills or melodies that seem to run across space, using the technique developed by John Chowning, except for the Doppler effect (this can be heard on track 1 of the Wergo 2013-50 CD recording : moving trills at 1mn29s, flying flute at 1mn43s, trajectories after 7mn05s, suggesting imaginary birds, with glissandi possibly hinting Doppler-like frequency shifts). The processing is intended to take the listener from an instrumental "reality" into a dream-like world, where the material constraints dissolve into fluid textures and flying sounds.

3 Processing to merge natural and synthetic sounds (*Sud*)

In 1983, François Bayle, then director of the Groupe de Recherches Musicales of Paris (INA-GRM), invited me to compose a piece. GRM was founded by Pierre Schaeffer, the inventor of musique concrète. My own activity had been mostly dealing with synthetic sounds : I decided to build this piece around the encounter of synthetic and natural sounds. These initially markedly different sound worlds would undergo transformations making them merge gradually. At GRM, the late Benedict Mailliard had developped efficient programs for processing sounds, and these programs, together with Mathews's MUSICV - often used internally in Mailliard's routines - afforded possibilities to transform sounds in ways that could be appropriate to my project of merging together the world of natural and synthetic sounds.

I assembled a few soundscapes recorded along the shore and in the country near Marseille: ebb and webb of the flow; roars of a mistral tempest; sea waves ringing in rock cavities; remote birds and voices; insect buzzes; seeds cracking in the sun; stridulation of crickets at night (the name of the piece is *Sud*.). I also collected a few other sound sequences: a short cello note ; bangings from wood chimes and metal chimes ; a fast arpeggio gesture played on the piano ; short sequences of tropical and equatorial birds songs from a recording found in Singapore. Some of the above soundscapes appear in the piece as "phonographies", akin to photographs, with only minor modifications or no modification at all, for instance the sea at the beginning, or the insect sounds toward the end of the first movement. Fifteen rather short recordings, lasting between 1 and 20 seconds, were selected as a kind of sonic kernel: these were subsequently submitted to several generations of processing, as described below.

In Marseille, I also generated some synthetic sounds with the MUSICV program. I chose a defective major-minor pitch scale, which does not exactly octaviate (G natural - B - E - F sharp - G sharp - B - E - F sharp - G natural - B - E - F sharp - G sharp ....), as the trade mark of synthetic sounds in the piece. Most of the synthetic sounds follow this scale. Although they were not generated in real-time, these synthetic sounds were conceived as gestures. For instance, I have specified ample arpeggios in terms of curves abstracted from wave contours and quantified to the steps of the major-minor scale. I also generated tones which appear to fly in space like birds: sine waves modulated in frequency by complex, supple, almost visible contours (I, 5mn50s, 6mn29s, 8mn50s; III, 56s, 4mn41s, 5mn45s). In contrast, the natural sounds I gathered - for instance songs of birds or crickets - originally comprise no pitches intended by the composer; they may even have no distinctive pitch, such as sea sounds.

Next I modified and proliferated my original sounds - most recorded, some synthetic - by submitting them to the transformations implemented by Mailliard in studio 123 at GRM. I hereafter describe various kinds of transformations and the way I used them for my project.

- First, *sound recording* is akin to photography: one must select the view point and the focus. Using sharp microphones as microscopes, I zoomed into the insect world to get close-ups of humming bees and cracking seeds in the summer heat (I, 5mn46s to 6 mn and 8mn26s to 8mn59s).

One also must *select* among the recorded material. Somewhat arbitrarily, I choose a found object - the sound of a wave, recorded a certain morning of june 1984 - to serve as a seminal cell used throughout the piece.

- With the GRM program BRAGE, one can *shuffle* sonic elements, i.e., control the division of sounds into short time fragments and the reassembling of these fragments in various ways. I used this "sound shuffling" to perform sonic developments from short sounds, such as wood chimes, (I, 3mn20s to 4mn36s) and to produce a "stuttering" piano, further processed by ring modulation (I, 4mn30s, 5mn ; III, 2mn16s to 2mn38s). Starting from "found objects" such as birds songs, I rearranged them compositionally to obtain first a pointillistic rendering, then a stretto-like episode. (I, 1mn42s to 2mn47s).

- A few sounds were *spatialized*. The piece is originally in four tracks, but it is often treated as dual stereo - back and front. Spatialization was performed on recording of birds to give the illusion of a controlled and somewhat (purposely) artificial movement of rotation. Thirty seconds after the beginning of the piece, a relatively slow movement is heard in the back of listener; then higher tones seem to rotate faster in front. Spatialization was also performed in the course of synthesis on "bird-like" tones modulated in frequency by supple and complex curves (I, 5mn50s, 6mn29s, 8mn50s ; III, 56s, 4mn41s, 5mn45s).

- I used *reverberation* to smooth certain processed sounds (for instance shuffled wood chimes), but I avoided it for recorded soundscapes, so as to suggest to the listener the actual spaces where they were captured. (This can be heard specially in the first three minutes or at the end of the first movement). I did add a little background reverb to reinforce the depth in illusory rotations.

- By *mixing* the sound to itself with a short time delay, I induced a pitch coloration: the pitch heard corresponds to a frequency which is the inverse of the delay. One can increase the degree of coloration by adding more copies shifted in time. I used this at the beginning of the third movement to introduce the color of a G sharp - an important pitch in the the major-minor scale permeating the piece (III, 0s to 39s).

- By *phasing* - mixing a sound with transpositions of itself with a minute frequency difference (say a twentieth of a Herz), one can turn steady periodic tones into a pattern where the harmonics of the tone wax and wane at different rates, proportional to the rank of the harmonic. This happens because the small frequency differences cause phase differences to slowly go from 0 to 360°: thus beats appear, with a period of 20 seconds for the first harmonic, but of only 2 seconds for the 10th harmonic, and of 20/n seconds for the nth harmonic. This produces an unexpected effect. It requires the precision of digital processing, and it is reinforced by the addition of more transpositions with the same frequency difference. I have used this trick before to animate synthetic sounds in a number of pieces: *Little Boy,* *Inharmonique, Songes*. Through phasing, I produced spectral scanning of cello tones, (III, 39s, 1mn24s).

I tried to submit non-periodic sounds to phasing : I applied the process to sea roars recorded a day of strong North wind - "mistral" : heavy sounds with wide spectra. The result came to me as a surprise: added to the sea sounds was a powerful glissando downward, starting shrill and deepening in spectrum until it finally got lost into low depths - not to reappear again. The explanation is not very simple, but the effect is quite strong - a "found effect", just as I used sonic "found objects". Its encounter made me decide to change my plan for the piece: the second movement would be a metaphoric tempest, scanned by these impressive descents, and with a catastrophic ending - a metaphor of a wreckage.

- Applying *time reversal* permitted me to obtain ascending curves from the preceding descending ones: an upward scanning cannot be obtained in real time, since the descent corresponds to the entropic loss of order, while an ascent would be a statistically impossible route from chaos to coherence.

- I also resorted to *mixing with enveloping and transposition*. I used this to shape synthetic inharmonic tones by energy fluxes of the wind and the waves of the sea (for instance at the beginning of the second movement). I used stylized amplitude contours extracted from actual dynamic curves found in recorded sounds, with frequency transposition intervals also calculated in accordance to these dynamic curves, but quantized to the steps of the major-minor scale (III, 3mn14s to 3mn30s and 4mn21s).

I also used transposition to exert control over certain pitches of the natural sounds. For instance, shortly before the end of the first movement, one can hear cricket-like chirps on the following pitches: G sharp, G sharp, F sharp, E, G natural, B. The crickets I recorded stridulated on F sharp: transposition made them follow the steps of the chosen scale (I, 9mn10s). In the third movement, low and slightly colored sea sounds are presented successively so as to be heard as G natural, B, E, F sharp, G sharp (III, 2mn51s).

- *filtering*. I extensively resorted to filters implemented by Mailliard. I used about 25 resonant filters tuned to the steps of the minor-major scale. Their impulse response increases when the bandwidth narrows. Very sharp filters are in effect oscillators: an excitation will make them resonate at the frequencies they are tuned to, and the long resonance will completely blur the temporal behavior of the excitation. One can view the array of resonant filters as a huge piano where the only raised dampers correspond to the notes of the major-minor scale. On the contrary, wider filters will do better in preserving the original identity of the excitation, but they will be weaker in the imposition of the scale.

As the reader may have gathered, real world sounds and synthetic sounds are made to come closer principally through two kinds of transformation (in addition to cross synthesis described below): 1) external morphologies from real world sounds are imprinted onto synthetic sounds; 2) the major-minor pitch scale is gradually imposed to real world sounds. In addition to transposition, the use of resonant filters tuned to the steps of the minor-major scale played a major role in the latter operation.

I applied such resonant filtering to various sounds: for instance the seminal wave contours which opens the piece can he heard filtered in the third movement, kind of liquidly singing and ringing to the scale. In the first part of the third movement, birds songs and caws are followed by their resonance. Later in this movement, I let a "bird raga" flourish by filtering a selected bird song through a set of relatively wide resonant filters: then other pitches than those of the scale can come through, which are heard as a kind of appogiatura preceding the E (III, 4mn06s to 6mn19s).

In the second movement of *Sud*, the pseudo bell-buoy and the sea sounds resonate in the manner of an organ. I obtained this by applying some of the above-mentioned transformations: resonant filtering creating an harmonic skeleton corresponding to the steps of the scale, and mixing several octave transpositions of motives (II, 36s, 57s, 3mn50s to 5mn).

- *modulation or cross-synthesis*. Starting from two sounds, the process of modulation or cross-synthesis produces an hybrid which combines certain characteristics of both original sounds. In the digital domain, *ring-modulation* is a simple multiplication of waves: from sine waves of frequencies f1 and f2, it produces additional components of frequencies f1+f2 and f1-f2. I have modulated piano arpeggios to make them inharmonic; they were then submitted to resonant filtering (III, 2mn16s to 2mn38s).

Linear predictive coding (LPC) is more elaborate. LPC analysis separates a sound into two parts: one primarily characterizes the excitation, the varying, dynamic, agogic aspects, whereas the other determines the response, the fixed, spectral, structural aspects. I thus crossbred sounds of different origins - birds with metallic plate or cello sounds; sea waves with wood chimes or synthetic "harpsichords". The former yields intriguing "chimeras" - bird-gong, bird-cello (III, 2mn04s, 5mn24s). The latter produces "waves" of wood chimes, waves of harpsichord (III, 1mn43s), thus imprinting on recognizable sounds the powerful energy profile of other sounds. (Note that the effect of a cross synthesis of this nature is much stronger that the mere imposition of an amplitude envelope taken from one sound onto another sound). My purpose was mainly to endow certain sounds with energy fluxes from other sounds, injecting specific qualities without necessarily confusing the identities -

like Cézanne wanted to merge "feminine curves with hill shoulders".

When one performs several generations of cross-synthesis, spectra can become very thick and dark. I resorted to the hybridization of sea sounds with wood and metal chime sounds for the catastrophical ending of the second movement. Even though the origin of the sounds gets confused, one still gets convincing suggestions of energy: for instance the excitation by metallic percussions is transformed, but its effect is still felt as powerful shocks (this can be heard at the end of the second movement).

As I already mentioned, I had selected a found object - the ebb and web of a wave on rough sand - as a seminal cell used throughout the piece. It appears at the beginning, and it later is repeated in different forms; its dynamic flux permeates the whole piece. It is imprinted onto other sounds, real or synthetic. It is even reflected in the form of the work, where many structures are build around the idea of the wave.

The formal scenario tells the story of the encounter between natural and synthetic sounds, first presented separately, and the growth of their mutual interactions - merging nature and artifice. The defective major-minor scale initially characterizes the artificial sounds, but it is gradually woven into the natural ones. The energy contours from natural sounds progressively print their mark over the synthetic ones. The compositional logic is not one of pitch: the pitch structure does not evolve; it is merely animated by dynamic fluxes.

4 Processing in pieces for instruments and tape

In *Voilements*, for tenor saxophone and tape, the soloist plays against his sonic shadow. The tape contains mostly saxophone motives recorded by Daniel Kientzy and processed digitally. The tape first echoes the soloist, multiplying his sound by means of delayed and transposed echoes - here harmonizer-like transformations were performed with the SYTER real-time audio-processor (cf. for instance on CD INA 2000, track 7, 1mn22s, 1mn45s, or 3mn49s to 4mn48s). This rivalry becomes more and more troublesome to the player : it alters its way of playing, it warps it, as a wheel which does not go round (the word "Voilements" alludes to a veil or a sail, but is also means "buckles" or warps"). The equal temperament tuning is eroded, the tension increases, up to a fight and a genuine crisis : melodic lines get twisted into loops (track 8, 12s). Then, as if there were a zoom backwards, the perspective changes (track 8, 1mn05s) ; the relation between the soloist and the tape is altered : the timbral range of the tape sounds expands, and the tape becomes a remote and pacific background for the gestures of the soloist.

Similar processes are used in *Lurai*, for celtic harp and tape, dedicated to Denise Mégevand, and *Attracteurs Etranges*, for clarinet and tape. The tape for this latter piece mostly comprises clarinet sounds recorded by Michel Portal and processed by computer in several ways - notably to achieve spatialization and time stretching. The piece stages dialogues and close encounters between the live clarinet player and the tape sounds. It tries to illustrate metaphorically the idea of *attractors* as geometrical descriptors of dynamic systems: punctual attractors, which correspond to equilibrium positions, and strange attractors - with a fractal structure - which correspond to chaotic systems with a destiny highly sensitive to initial conditions. The wind instruments occasionally resort to turbulent flows and multiphonics, which are instances of chaos. The unfolding of the piece uses polar pitches, cycles or quasi-cycles and bifurcations.

5 Processed voice : *Invisible*

The title of the piece refers to Italo Calvino's book *Invisible Cities*. The principal sonic material is the recorded voice of Irène Jarsky speaking or singing texts - mostly translations into French of quotes by the Tao poet and philosopher Tchoung-tseu, but also fragments of poems by Basho, Dante, Heine, Longfellow and others, read in their original languages. I also used sounds of natural origin: rain, thunder, wind, birds. These natural sounds often intervene in a plain way : but they are also transformed and combined to other sounds, natural or synthetic.

I used Daniel Arfib's program SOUND MUTATIONS to perform intimate modifications of sounds. Thus, in order to echo Tchouang-tseu's evocation of breath as void capable of modeling itself to external objects, I have performed cross synthesis of wind sounds with speech, replacing in effect the vocal chords of the soprano by the blowing of the wind (7mn36s to 7mn45s). I have also slowed down the sound of the word "langsam" (german for "slow") without frequency transposition, to echo Heine's evocation of the sluggishness of time (9mn43s to 9mn56s ; cf. also at 30 s and 8mn28s the stretching of "die Zeit"). The rate of time expansion can be higher than 100 : however the consonants are not expanded, so that the spoken words remain intelligible. The name "Chloé" is also slowed down at a variable rate, reckoned to follow a composed melodic contour (10mn40s). I performed similar transformations on the spoken expression "une sensation de vide" (a sensation of void or vacuum) to get a musical development similar to variations on a theme (5mn15s to 6mn20s). To illustrate "la voix et le son s'harmonisent" (voice and sound harmonize each other), I imprinted the same harmonic pattern onto both synthetic "bells" and the soprano's voice (11mn05s to11mn50s). In the previous cases, computer processing permits to preserve the identity of the sound origin while transfiguring its time scale, hence its dynamic behavior, as well as its inner harmony. Here composition specifies time within sound objects, rather than setting sound objects in time.

I synthesized bell-like tones to compose them as minor chords, as in usual bells, but also as major chords - to echo a poetic suggestion by Tchouang-tseu: zephyr produces a minor harmony, squalls a major harmony (6mn50s to 7mn10s). In several sections, I also controlled the synthetic acoustic environment (3mn29s to 3mn40s). Sonic transformations bring the voice in a fictitious, virtual acoustics, which does not come from the bouncing of sound waves against solid obstacles: but of course we interpret this acoustics by assuming a space where the sounds travel (2mn25S to 2mn32s). Specifying the acoustics and its transformations is part of the composition; the space which the listener is lead to imagine has connotations that must be taken in account.

Resorting to digital synthesis and processing thus permits to implement immaterial processes, to produce illusory voices, to set the sounds in imagined spaces similar to Calvino's invisible cities - even though Calvino's imagination is more agile and varied than the sound simulacra I was able to produce.

6 Electroacoustic pieces: *Avel, Elementa*

In my latest pieces, *Avel* (1997) and *Elementa* (1998), realized at GRM, Paris, I used most of the processes described above. *Avel* is a study about the wind. The piece begins with a "phonography" (a sound photography) : then it evokes eolian sounds - flute, harp - and goes up and down while stylizing the whistles, whines and howls of the wind. Swaying harmonies are activated by these energy fluxes.

Elementa was completed in 1998 for the fiftieth anniversary of "musique concrète". The piece includes sounds synthesized with the MUSICV program and the Synclavier synthesizer, but the sound material mostly consists of recordings. The nature of the sound sources is not hidden : the evocation of the four elements - *Terra, Aqua, Aer, Focus* (earth, water, air, fire) - takes advantage of recognizable sound recordings. The composition relies upon the connotations and the symbolic implications of these recordings.

Elementa was realized using Pro Tools and GRM Tools. GRM Tools serve as "plugs-in" for the Pro Tools program, permitting to control audio effects such as time shuffling, spatialization or filtering. For instance, in the second movement, *Focus*, recordings of fire sounds are spatialized to suggest elaborate movements of the fire around the listeners ; also comb filters react to the explosions in the sound to generate complex percussive rhythmical patterns that mirror the fire's internal rhythm. The recorded sounds are weaved into figures, phrases, developments and sections, together with synthetic figures with related "gaits" : a compositional processing, careful to preserve the autonomy of organic sound objects and their dynamics of flux, duration and energy.

7 Conclusions

It seems to me that the increasing refinement of available audio effects bridges the gap between the resources of synthesis, with the precise and ductile control it affords, and those of processing, with its inexhaustible variety of content.

Although I fully realize the interest of real-time and reactivity, I must stress that most of my compositional work in this field implies freeing the elaboration of the pieces from the constraints of real-time.

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