Interaction, Convergence and Instrumental Synthesis in Live Electronic Music

Danilo Rossetti[1]

[1] Institute of Arts University of Campinas/CICM Université Paris 8
danilo_rossetti@hotmail.com

Abstract. In this article we present and discuss the interaction and convergence between the instrumental and electroacoustic parts in live electronic music. Our approach is related to the idea of sound morphology, based on the undulatory and granular paradigms of sound. We also analyze the process of instrumental synthesis based on frequency modulation (FM), in order to generate pitches and enable timbre interpolation. For these purposes, we address some examples in our works *Oceanos* (for sax alto), *Poussières cosmiques* (for piano) and *Diatomées* (for instrumental ensemble), all of them with live electronics. We conclude comparing the analyzed operations with the emerging form of these works considering both the micro and macro temporal aspects.

Keywords: Live electronic music, interaction and convergence, undulatory and granular paradigms, frequency modulation, timbre interpolation.

1 Introduction

When we think about live electronic music, one of the first problems that arise is the interaction between the instrumental acoustic and electroacoustic parts of a work. It means to imagine how to make these two sound sources merge together and sound as a unity of form, as one single timbre. This interaction can be analyzed considering several aspects related to electronic treatments.

In live electronics works, instrumental sounds are captured, treated and the electroacoustic resultant sound is diffused during the performance. They can also be recorded in a support during the performance for subsequent electroacoustic diffusion. In deferred time compositions, the electronic part is fixed in a support, which means the performer(s) must follow the tempo of the electronic part. There is also the question about multichannel spatialization of the generated sounds. One possibility is to conceive them as punctual sources that perform trajectories in the acoustic field; another possibility is the use of an ambisonics spatialization tool which decodes the produced acoustic field in spatial harmonics, similarly to sound decomposition in frequency partials.

We will approach the interaction aspects from the sound morphology standpoint. In this sense, the acoustic sound generated by different instrumental techniques can be combined with the chosen electronic treatments. This means that, in compositional processes, it is possible to converge acoustic sounds and electronic treatments in relation to similar sound models. We expect, as a result, that this idea of convergence will amplify the instrumental possibilities, thus generating new sonorities to be diffused.

Our sound morphology view is based on composition and sound analysis considering both the undulatory (continuous) and granular (discontinuous) paradigms of sound. This approach is slightly different from the notions proposed by Schaeffer [1] and Smalley [2], which are based on a sound object *solfège* or on a listening typology (auditory description). Our approach is mainly focused on the compositional process, which can be a live electronics process, seeking to converge the instrumental and electronic parts.

We do not think of the undulatory and granular models as the only possibilities to build instrumental and electronic timbres, nor as dialectally opposed. Rather, we think about these two models as complementary, i.e. as a tool that can guide us in processes of timbre fusion. Concerning these paradigms of sounds, we will analyze some examples (scores and sonograms) from our live electronics works *Oceanos* (2014), for alto sax, and *Poussières cosmiques* (2014 – 15), for piano.

We will also analyze Gérard Grisey's concept of instrumental synthesis [3], which is strictly connected with the works of spectral composers from the 1970s. Generally, in acoustic or live electronic music, instrumental synthesis would be the simulation of electronic compositional procedures in instrumental composition. In the examples we will present, frequency modulation synthesis [4] will be addressed in the instrumental context.

Our analysis also includes the use of irrational numbers as indexes of modulation, to generate new inharmonic spectra and timbres. Our examples concern compositional procedures of our work *Diatomées* (2015), for instrumental ensemble and live electronics. Our final considerations will address the interaction and convergence in live electronic music, including the interaction produced between micro and macro events in order to generate musical form.

The electronic part of the analyzed works is conceived in Max, working with objects of HOA (High Order Ambisonics) Library, developed by the CICM (*Centre de recherche Informatique et Création Musicale*) of *Université* Paris 8. Using the *process~* object of this library, and choosing a mono source file as input (pre-recorded or captured live with a microphone), we can address treatments such as reverb, delay, granulation, ring modulation, microtemporal decorrelation and convolution, combining them with an ambisonics multichannel spatialization. More specifically, this paper will discuss ring modulation, granulation and microtemporal decorrelation examples.

2 Undulatory and granular paradigms of sound

The undulatory paradigm is related to continuous structures, considering that the sound pitch is defined relatively to the sustained part of the sound envelope. In the 19^{th} century, modern psychoacoustic was structured having, on the one hand, the research of Helmholtz [5] and Ohm and, on the other hand, the research of Seebeck [6]. Helmholtz and Ohm presented an undulatory model based on the Fourier series. When the human ear perceives a sound, it performs a real time spectral analysis where the lowest partial defines the pitch. In 1841, based on his experiments with a siren sound, Seebeck observed the presence of a "periodicity pitch", which means that even when the fundamental frequency of a given sound is missing, we can still perceive it as having the same pitch. Seebeck concluded that not only the fundamental frequency but also the upper partials determine the sound pitch [7]. According to this view, pitch perception is the result of harmonic fusion into a single sound.

In the 1950s, Meyer-Eppler [8], among others, conducted research, observing the triple pitch quality and the presence of an effect called "formant pitch". Considering the triple pitch quality, the first is its absolute pitch, running parallel to the frequency; the second is the chroma, a quality which recurs cyclically within each octave (for frequencies of up to 4.500Hz); the third is Seebeck's periodicity pitch. If, in a periodicity pitch experiment, the continuous "mutilated" note (without the fundamental) is interrupted for approximately one second, the sensation is completely altered. Instead of the "residual tone", we hear a new pitch which lies in the region of the strongest remaining partials. This new perceived structure is the formant pitch. In the 1970s, Terhardt [9] conducted research, defining the terms "virtual pitch" (which corresponds to Seebeck's periodicity pitch and the synthetic mode) and "spectral pitch" (which corresponds to Helmholtz and Ohm's analytical mode).

The granular paradigm is associated with discontinuity having Gabor's acoustic quanta theory [10] as basis, whose heritage is the wave-corpuscle duality of quantum physics. Gabor conceived a sound description method that combines two other methods normally employed for this purpose: time-function description of sound and Fourier frequency analysis. Gabor presented the hypothesis that a sound is composed of innumerous quanta of information, which are described from time and frequency variables (p. 435). His hypothesis is defined in analogy to the corpuscular theory of light, which states that a stream of light is formed by a continuous, granular texture. Under this approach, according to the information theory, the acoustic signal can be divided into cells, with each cell transmitting one datum of information. Any acoustic signal can be divided into cells, and the whole of this representation corresponds to the totality of the audible area, in terms of time and frequency.

Iannis Xenakis, inspired by Gabor's theory, developed a granular theory in the music domain [11] as a part of his Markovian stochastic music. According to his theory, every sound is conceived as an integration of grains (elementary particles, sound quanta). These grains have a threefold nature: duration, frequency and intensity. It is important to highlight that, according to Xenakis's stochastic music theory, traditional musical notions such as harmony and counterpoint are not applied. They were replaced by notions such as frequency densities (considering a given period of time), grain durations, and sound clouds.

In a compositional process, the most important variables related to the granular paradigm are mainly based on temporal structures (e.g. grain size, grain delay and feedback, cloud density) and linked to ideas of time and rhythm, which can be synchronous or asynchronous. The undulatory paradigm, on the other hand, is mainly connected with the frequency universe, since its most important variables control frequency values, for example, the organization of partials in a certain sound. However, this does not mean that there are no frequency variables related to the granular paradigm (we can define, for instance, the frequency band of a sound cloud) or that there are no temporal definitions concerning the undulatory paradigm (for instance, we can define the duration of each partial of a sound).

3 Interaction and convergence

Here we will present two examples of our pieces *Oceanos* and *Poussières cosmiques* considering ideas of interaction and convergence, based on the undulatory and granular paradigms of sound. In both works, instrumental sounds are captured by microphone and processed in real time in our Max patch (electronic treatments and spatialization).

3.1 Undulatory paradigm

In the first example we address a fragment of the piece *Oceanos* (2014), for alto sax and live electronics. The figure below (Fig. 1) shows a multiphonic played by the saxophonist[1], which is combined with the electronic treatment known as ring modulation [12]. This combination between instrumental writing and the chosen electronic is conceived to achieve a morphologic interaction between these two means. The multiphonic has a spectral configuration represented by a superposition of partials above a fundamental frequency. The ring modulation is an electronic process based on the interaction of two sound waves (carrier and modulation frequency). The result of this operation is the generation of new frequencies whose values are the sum and the subtraction of the carrier and modulation frequencies.

In our example, the modulation frequency is the sound of the saxophone (captured by the microphone), while the carrier frequency is set at 13.36Hz. This value corresponds, in terms of octaves, to the G three quarters of tone higher, which is the multiphonic basis pitch[2]. In ring modulation, when modulation frequencies under 20Hz are used (the lower limit of audible frequencies in humans), we perceive a rhythmical effect known as tremolo, due to the produced amplitude modulation. This rhythmic perception is equivalent to 13.36 oscillations per second. Below, on Fig. 1, we can observe the score and sonogram of said fragment of the piece. In the score, we have the multiphonic writing including the produced pitches; in the sonogram we can observe the time and frequency distribution of the resulting sound (instrumental sound and its electronic modulation).

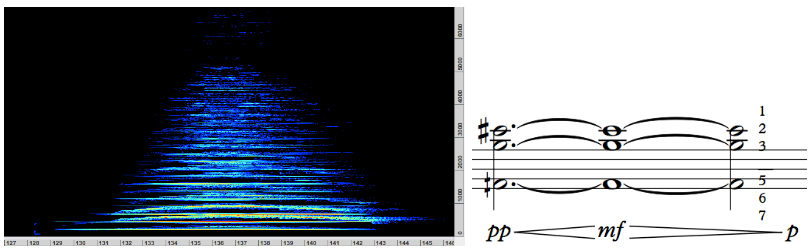

Fig. 1: Combination of a multiphonic with a ring modulation process (sonogram and score)

3.2 Granular paradigm

[1] In this recording, the piece was performed by José de Carvalho.
[2] Transposed score.

The second example intends to show an idea of interaction and convergence between instrumental writing and electronic treatments in our work *Poussières cosmiques*[3] considering the granular model of sound. The figure below (Fig. 2) shows in the piano writing that the pitches are concentered in the extremely high register (measures eight to eleven). Sixteenth notes with slightly different rhythms are written for both hands in order to produce minimal temporal offsets between the two voices. The tempo, in this passage, starts with a quarter note equal to 48 and grows up to 90. As we can notice, the left hand rhythm is maintained constant with sixteenth notes, while the right hand executes rhythmic variations such as 5:4, 6:4, 7:4, 9:8, 11:8 and 13:8.

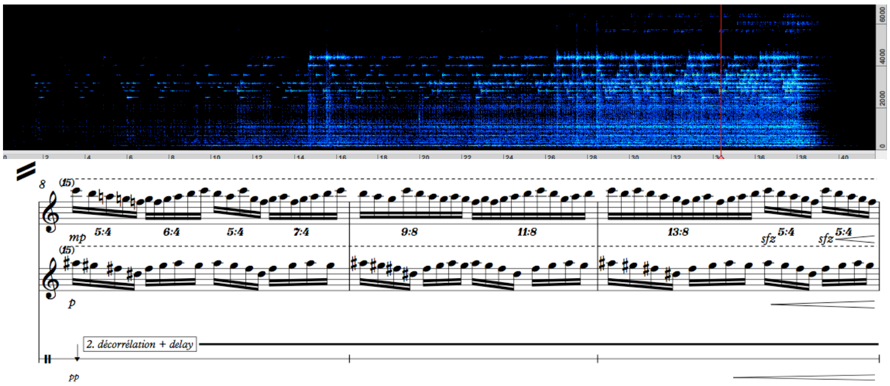

Fig. 2: Sonogram and *Poussières cosmiques score* (measures 8 to 11)

The minimal temporal variations between these two voices produce an asynchronous perception in listening, similar to granular synthesis processes (with larger grains compared with the grains of an electronic granular synthesis). In convergence with this pianistic writing, we addressed microtemporal decorretation and delay as treatments to create a diffused sound field. This procedure emphasizes the generation of a granular and discontinuous resulting sonority. In the sonogram below, we can observe some characteristics of the granular paradigm such as the presence of a sound mass whose density evolves in time. Considering the global perception, this granular mass is fused with the pitches played by the pianist.

The microtemporal decorrelation [13] is an electronic treatment similar to the delay which generates microtemporal offsets in space and time between the produced audio tracks, which are diffused in a multichannel system. Through this minimal offsets and also depending on the sound phase (considering a 360º plan) we can produce changes on the spatial perception, creating a diffused sound field.

In order to promote the interaction of acoustic and electroacoustic sounds, we converge the granular writing of the piano with electronic treatments such as the microtemporal decorrelation and the delay. This operation results in an amplification (in terms of quantity of information in space and time) of the morphologic qualities found in the piano sound.

[3] Performed by Sophia Vaillant (live recording).

4 Instrumental synthesis

The definition of instrumental synthesis (*synthèse instrumentale*) can be found on the well-know text of Grisey [3] ("A propos the la synthèse instrumentale", 1979, 35 -- 37). In relation to this concept, Grisey states that the advent of electroacoustic music enabled composers to explore and manipulate the morphology of sound in its interior, and then to manipulate the sound in different time scales (from microphonic to macrophonic).

According to Grisey, access to the microphonic universe is only possible through electronic or instrumental synthesis. The electronic synthesis is a microsynthesis because from its different technics (additive synthesis, amplitude, ring or frequency modulation, etc.) we can generate the internal components (partials) of a resulting sound. Instrumental synthesis involves a modelization process where the instrument is used to play each internal component of an analyzed synthetic timbre. In this process, each partial of the analyzed sound is played as a pitch by a determined instrument. Consequently, a new series of partials is produced for each acoustically performed pitch.

In order to describe the instrumental synthesis process employed in our work *Diatomées*[4] (2015) for violin, bass clarinet, harp, percussion and live electronics, we address some considerations of frequency modulation synthesis, according to John Chowning [4]. Frequency modulation is a kind of modulation between two signals (a carrier and a modulating frequency) that produces spectral modifications in the generated timbre along its duration. As Chowning explains, "In FM, the instantaneous frequency of a carrier wave is varied accordingly to a modulating wave, such that the rate at which the carrier varies is the frequency of the modulating wave. The amount of the carrier varies around its average, or peak frequency deviation, is proportional to the amplitude of the modulating wave" (p. 527).

Another quality of FM synthesis is related to the carrier and modulating frequencies and values of index of modulation which fall into the negative frequency domain of the spectrum. These negative values are mixed with components of the positive domain. According to the FM synthesis formula, if the index of modulation corresponds to rational numbers, harmonic spectra are generated, if it corresponds to irrational numbers, inharmonic spectra are generated. In our view, irrational values of indexes of modulation can generate very interesting timbres and constitute a huge universe to be explored. In *Diatomées*, we employed FM instrumental synthesis procedures from both rational and irrational values of indexes of modulation, which are described below.

In order to generate the main scale of the piece (used in A to C parts), we performed a FM instrumental synthesis from the interval between Bb4 (464Hz) and A2 (110Hz), considering the Bb4 as the carrier and the A2 as the modulating wave. The figure below (Fig. 3) shows the obtained frequencies (and the corresponding pitches) from the first seven modulating indexes (1 to 7). The quarter of tone division of the octave is employed. The arrows indicate slightly deviations in the corresponding pitches (around one eighth of tone).

[4] Performed, in this recording, by the Ensemble *L'Itinéraire*.

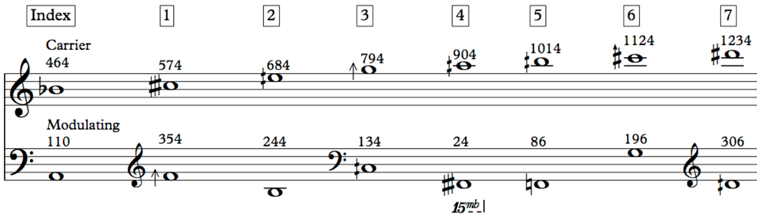

Fig. 3: Main *Diatomées* scale, generated by FM instrumental synthesis

In the D part (last part of the work), the idea was to apply degree of changing (*degré de changement*) as proposed by Grisey [3] in his article "Structuration des timbres dans la musique instrumentale" (1991). This is a method to gradually interpolate different timbres in time. The pitches obtained in the first instrumental FM procedure are considered as having an index of modulation value of 1. We gradually distorted the original spectrum from the multiplication of its frequencies by irrational numbers such as $2^{1/5}$ (1.15), $2^{1/4}$ (1.25), $2^{1/2}$ (1.41) and $2^{4/5}$ (1.74).

In the figure below, we address the new obtained spectra, which are vertically organized and separated in semitones and quarters of tone to provide better visualization. The moment of timbres transition in the piece is highlighted by the presence of Thai gongs notes. This transition also involves pitches from some precedent and posterior measures in order to achieve a gradual interpolation between timbres.

Fig. 4: New timbres obtained from gradual inharmonic distortions of the original spectrum

5 Operations in micro and macro time

Based on the interaction and convergence between instrumental and electroacoustic universes, live electronic music provides innumerous possibilities of new sound generation with aesthetic qualities. These new sound morphologies are the result of timbre fusion between different structures that are perceived as a single unity.

According to our view, concerning the undulatory paradigm in microtime domain (formed by events whose duration is inferior to the note limit), the interaction between acoustic and electroacoustic means is focused in frequency operations. These operations intend to reinforce some partials that are common to both means and also to aggregate new ones in the resultant sound. These operations always consider a continuous timbre.

In relation to the granular paradigm, the interaction is based on discontinuous events, which are mainly modulated by time values. For instance, we can combine a granular electroacoustic texture (with grains up to 100ms of duration) with instrumental grains whose duration is longer. For this purpose, we must imagine instrumental techniques that produce discontinuous sonorities such as the *staccato* and trills, *jeté col legno* on strings, or *frullato* and slap tongue sounds, on aerophonic instruments.

Considering macrotime events (notes and their combination in time), it is possible to apply instrumental synthesis procedures aiming to generate pitches and scales that will be used in the composition process. In terms of form generation, we can apply the idea of timbre interpolation as we approached in *Diatomées*'s compositional process. Aesthetically interesting timbres can be produced from irrational values of frequency modulation indexes. These spectra can be distributed in different ways in the score, so as to allow timbre interpolation.

In this article, we intended to present different possibilities of interaction and convergence in live electronic music. Based on the operations presented and discussed herein, micro and macrotime issues were approached, in order to produce a formal coherence in the analyzed works. Micro events interfere on each other by means of close contacts between sound particles (grains or partials). At the same time, the macro form is being constituted by means of a continuous modulation, which constitutes the perceived musical form in listening.

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