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INTRODUCTION

In recent years, live electronics have become an integral part of the new music world; nevertheless, the means of notating such music remain largely incapable of transmitting the composer's intention in a consistent and reproducible manner. As the performance of works using live electronics grows increasingly frequent, the necessity of systematic notation can no longer be ignored.

Through my experience in the fields of composition, performance and notation of live electronic music, I have had the opportunity to gain different perspectives on the complexities of the topic. As a composer, I have encountered the difficulties involved conveying one's musical and technical intentions in as universal manner as possible; as a technician, I have spent long hours puzzling over a composer's lacking notation; as a notesetter, I have dealt with the many practical constraints imposed by editors, ensembles, halls and institutions that hinder composers from investing time and energy in notation of electronics.

This experience has led me to understand that the development a single, all-purpose notational system that responds to the varied possibilities of live electronics is merely a fantasy. However, despite the endless possibilities, multifarious compositional methods and diverse implementations, one can observe many common obstacles in the notation of electronics. Since these obstacles have shared causes and outcomes, it is possible that a specialised notational system may serve several purposes. Thus, a largely uniform spectrum of solutions for the notation of electronics may be generated using a finite number of notational systems.

The goal of this research is not to codify and present these possible systems, but rather to identify and classify the issues that a notational system should treat. To this end, the historical, social and practical aspects of notation of electronics will be discussed in order to clarify the origins of its many complexities; then, the three compositions of differing aesthetics and techniques will be examined so that their advantages and shortcomings may serve as a basis for the development of future notational systems.

I. BACKGROUND

I.1. PRESCRIPTIVE VS. DESCRIPTIVE NOTATION

A primary distinction that must be made before approaching notation of media heretofore unnotated is that between prescriptive and descriptive notation. In his article in *The Music Quarterly* in 1958, Charles Seeger aptly names and describes these two types of notation. Prescriptive music-writing is “a blueprint of how a specific piece of music shall be made to sound”, while descriptive writing is “a report of how a specific performance of it actually did sound”.

In traditional music-writing, the two types of notation are consolidated: the symbols of traditional notation indicate both which gestures should be made in order to perform the work, and how it will sound. This is due to the century-long development of a musical culture that allows musicians to immediately translate a written note to an action – such as blowing, pressing a finger, striking a key – that will produce that note. This same culture, along with sufficient aural training, allows musicians to look at a notated work and imagine how it is expected to sound. Likewise, the timbre of a written passage can be easily understood if it employs only classical instruments played in a standard manner: trained musicians know how a violin or trumpet sound, and generally even know how certain sound-altering extended techniques such as *sul ponticello* or mutes sound. Thus, the standard two dimensional system in which pitch is notated vertically, time horizontally and timbral elements written in words, has served both a prescriptive and descriptive function until the twentieth century.

Needless to say, this system has many shortcomings: the notation of any music external to the European tradition, or whose primary parameter is not pitch and whose rhythms do not adhere to a regular beat structure, cannot be properly represented by traditional notation. This problem became eminently clear in the second half of the twentieth century as new playing techniques were invented and influences from non-European music entered the classical music world. How should a previously unheard of sound be notated? How can a new unusual use of an instrument be explained? In such cases, the composer can rarely to find a notational system that is both prescriptive – and can dictate how to create a sound with an instrument – and descriptive – and can clarify what will be heard as a result.

In electronic music, this dichotomy is even more extreme, as this medium offers endless possibilities. Any operational instruction given and any description of a sound is unlikely to be valid for more than a very limited number of works, as each new piece bears the potential of inventing yet new sounds and new means of producing them. Therefore, in determining the most appropriate method of notating live-electronics, one must seriously consider the importance of the prescriptive and descriptive aspects of notation.

Ideally, a notational method will be able to include both prescriptive and descriptive elements. However, depending on the composition and the role of the electronics, one approach may be more propitious than the other. If a piece contains complicated electronics, for example, that react with some degree of randomness to an instrumental part which may also be aleatory, the use of descriptive notation is unlikely to be fruitful; such unforeseeable sound results are impossible to describe reliably. In an equivalent situation it may be more useful to provide the sound engineers with instructions as to what they are to do, which processes to operate and when to shut them off, which signal inputs or outputs to reinforce, etc. The sound engineer will unfortunately not know which sound result to expect and therefore cannot ascertain that the desired outcome was achieved; however, the instructions will allow complex processes to be carried out with minimal confusion.

If a piece contains electronics that are more precisely predefined both in terms of time and frequency, or if the composer has a clear sound result in mind that may be reproduced by a variety of means, a descriptive notation may be a more felicitous choice. In the first case, a large portion of the electronics may be automatised; consequently, the sound engineer is not required to carry out many tasks, and does not need operative instructions. The descriptive instructions may prove more valuable, as the engineer will have an idea of the sound result and be able to adjust the electronics accordingly. Likewise, in the second case, precise operative instructions may only hinder the work of the sound engineer if they do not take into account variations in material and room acoustics. In such a situation, the prescriptive instruction to raise the volume of the electronics by 3 dB in comparison to the musicians, for example, is much less appropriate than the descriptive instruction to ensure that the electronics should sound one degree louder than the musicians. Depending on the hall, the microphones and loudspeakers used, as well as the position of the players and their dynamic capabilities, 3 dB may be too little or too much. However, if the composer's intention is clear, the sound engineer will find a means of realising the desired result.

Considerations concerning the prescriptive and/or descriptive nature of various methods of notation will therefore regularly be raised over the course of this paper.

I.2. Common Issues

I.2.1. Lack of Notation

One of the principal problems encountered in the performance of mixed live-electronic works is the utter lack of any indications in the score concerning the nature or operation of the electronics. This issue may arise for one or more of the following reasons:

1. The composer conceives of the electronics as a phenomenological experience liberated from the analytical constraints of notation. This strongly ideological perspective has its origins in the beginning of the musique concrète school, which attempted to break from systematic methodology of traditional concert music.
2. The composer performs the electronics himself, is aware of the details of its performance, and therefore deems it unnecessary to make note of his work. Generally, if and when a third party requests to perform the electronics and is granted permission, the composer rarely finds the time to translate his experience into intelligible notation.
3. The electronics are entirely automated by a computer programme that controls all parameters of the electronics in performance and therefore prescriptive indications are unnecessary. Likewise, descriptive indications merely serve for reasons of historic interest, since neither performers nor sound engineers are required to follow the score.

4. The piece is composed in a two-step process: first the instrumental parts are written and only then are the electronics finalised. This may be due to a musical conception in which the electronics are secondary to the instrumental/vocal writing and are therefore developed after the instrumental/vocal score is complete, or to a simple pragmatic response (as is often the case) to the fact that musicians must receive their parts well in advance while the electronics may still be modified on the very day of the performance. After the performance, the composer does not bother modifying the score to reflect the electronics that were conceived shortly before the performance.
5. The electronics are realised by a technical assistant working with the composer. As the composer does not sufficiently understand the functioning of the electronics and the assistant does not sufficiently understand the notational language of the composer, neither are in the position to produce a useable score.
6. Music editors, commissioning bodies, studio providers and all other organisations involved in the financial and practical production of a live-electronic work and its score, either overlook or do not take responsibility for the documentation process, which can be costly and time-consuming. It is in the interest of neither the composer nor the sound engineer to engage in such a large and unremunerated task.

Of these explanations, the fourth is certainly one of the most frequent while the fifth and sixth are also quite common. Thus, the lack of electronic notation is in many cases due – whether directly or indirectly – to practical and financial reasons.

I.2..2 Lack of a uniform system

The many scores that do not suffer from the aforementioned lack of any indication regarding electronics are victims to another significant notational issue: the lack of a uniform system for the notation of electronics. This is neither an isolated nor uncommon problem. For much of the last century, composers of acoustic music sought new methods of representing sounds that could no longer be conveyed by the pitch-and-rhythm oriented symbols of traditional notation; this resulted in the profusion of heterogeneous, seemingly unrelated symbols. A more uniform notational syntax for contemporary music emerged decades later, as the use of certain sounds and extended techniques became more commonplace.

Contemporary music notation thus underwent a process that brought it closer to the effectiveness of traditional notation. Take for example overpressure on a string instrument: though this sound was originally represented in a variety of ways ranging from simple symbols to graded systems showing the degree of pressure (and still is in some cases today), at present it is largely notated using one of two or three symbols. As young composers learn from the scores of the previous generation and young performers are taught to interpret these very scores by their teachers who perhaps premiered the work, a written and oral tradition is formed. As this process is repeated, both a prescriptive and descriptive significance is bestowed upon the specific set of symbols for overpressure. They indicate both how to play the instrument (excessive pressure, little horizontal motion) and what sound should be produced (a distorted, scratchy noise), just as traditional notation serves both as playing instructions and as an aural description.

Unfortunately, this unifying, tradition-building process can rarely be observed in notation of electronic music for several principal reasons:

1. Unlike instrumental or vocal sounds, electronic sounds can be generated by an infinitely wide variety of means. To produce a reverberation effect for example, the sound engineer may use an analogue reverb, any number of digital reverbs functioning as independent plug-ins, a self-constructed digital reverb in a signal processing programme such as Max/MSP or Pure Data, a digital or analogue reverb from a mixing desk, etc. Furthermore, the operation of each of these options may require a different gesture: the displacement of a fader or knob, the push of a button, etc. Thus, a single symbol or word in a score cannot reliably convey a physical instruction to the sound engineer, unless specific equipment is delivered with the score.
2. Methods of electronically treating sound vary immensely; there are as many approaches as composers. A notational system may correspond well to precise, highly synchronised electronics, but not at all to long, performer-dependent

processes. The choice of treatment (timed, open-ended, pre-determined, chaotic, random, etc.) as well as the manner of vocal/instrumental writing (exact, aleatoric, etc.) defines a set requirements for the notation. As an infinite number of combinations of methods exists, it is impossible to envisage a single notation that would accommodate this plethora of possibilities.

3. Live electronics are highly dependent on the incoming signal from the performers. In many cases it is difficult to predict how dynamically the musician will perform; in music of an improvisatory nature, it is almost impossible to predict what the musician will do. Consequently, neither descriptive indications of the sound result nor prescriptive indications of the work to be carried out by the sound engineer can follow a predetermined notational system.
4. In most attempts to notate electronics make use of graphical notation. Unlike traditional notation, which is limited to a set of symbols and variations thereof, graphical notation is limitless. Even newly invented symbols for contemporary acoustic music are mere modifications of traditional symbols and can be quantified within the traditional staff system. Freed form these constraints, graphical notation may be used in multifarious ways as each composer may (and generally does) have an individual manner of visualising sound. The task of rendering such idiosyncrasies uniform outside the limits of a general notational frame is not easily achieved.

As can be extrapolated from the reasons stated above, it is indeed the great variety and seemingly endless possibilities provided by the electronic medium that render impossible its notation within a confined system.

I.2.3. Acoustics and material

Yet another set of factors that plays a very important role in the performance of live electronics and that is difficult to account for in notation, is acoustics. The effectiveness of live electronics may vary immensely as a function of the hall and the equipment used, elements that inevitably change from one performance to another. Though acoustics obviously affect instrumental/vocal music as well, the differences in less extreme and simpler to control. Upon hearing that his sound is modified by the acoustic conditions of a hall, a musician may make the necessary adjustments by ear, as he masters his instrument and has a clear idea of the desired sound.

An electronics engineer in a similar situation must handle a much greater number of variables and unknowns. Without being familiar with the hall, the she is not aware of which acoustical properties most drastically effect the sound: diminution or amplification of specific frequencies, unevenness in the propagation of sound from the stage to the rest of the hall, lack or abundance of reflection points. Likewise, without having worked with the microphones or loudspeakers, the she cannot know which changes in the electronics are effected by the idiosyncrasies of the material. Thus, in order to make the proper adjustments, the engineer must have sufficient time to familiarise herself with both the hall and the equipment and to test their reactions in a variety of situations. Unfortunately, due to financial considerations, this is a rarely allotted privilege.

Furthermore, in order to properly identify the changes to the electronics and the necessary adjustments, the electronics must be tested and modified with the instrumentalists/vocalists. However, sufficient time in the hall with the players is rarely available; additionally, players rarely have the necessary patience to repeat the same passages and wait while the engineers diagnose the and attempt to correct the problems. Rendering the situation even more complicated is the fact that the desired sound is rarely known by the engineer.

These issues are impossible to reflect in a score, as a composer cannot provide a separate score for each hall used and each set of material. It is also unreasonable to request that a work be performed only in one hall using the same material. Therefore, notation of live electronic music must carefully consider which elements of the electronics should be notated with greater flexibility and using more universal indications, so that the work may easily be adapted to new acoustic situations.

II. EXAMPLES FROM THE LITERATURE

In order to further illustrate the notational challenges faced by both composers and sound engineers when approaching the creation or performance of a live-electronics work, three compositions will be discussed in detail and their notational methods analysed. The three pieces chosen for this purpose represent a broad spectrum of compositional methods, aesthetic convictions and technical means: *Voi(Rex)* (2002), by Philippe Leroux, make use of precise and largely controllable electronics corresponding to discrete events in the piece; *Mixtur* (1964), by Karlheinz Stockhausen, makes use of analogue apparatus whose operational instructions are clearly defined, yet whose sound-results remain unpredictable; *Hypermusic Prologue* (2009) by Hèctor Parra, employs an extremely complex web of processes and treatments, which are thoroughly controlled in principle yet highly variable in practice.

II.1. *Voi(Rex)* – Philippe Leroux

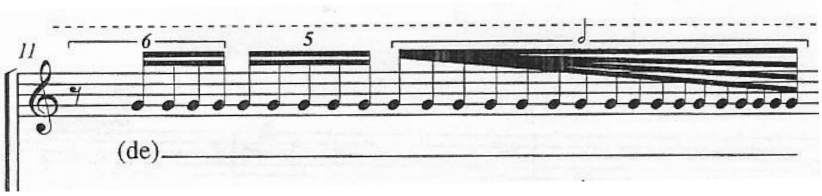
II.1.1 Background

Voi(Rex) was written for voice, ensemble of 6 players, and electronics, and premiered in IRCAM in 2003 by Ensemble l'Itinéraire and Donatienne Michel-Dansac. The piece comprises five movements, each based on excerpts from Lin Delpierre's poetry collection, *Le Testament de fruits*. The prevailing idea behind Leroux's compositional process is the use of various models as well as their juxtaposition and opposition throughout the work.

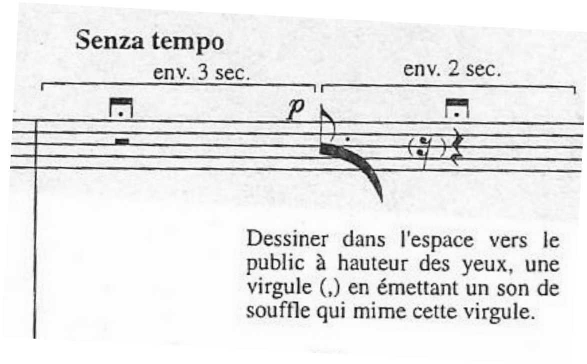
As in most of Leroux's mixed and electro-acoustic pieces, electronics are integrated on numerous compositional levels, both local and global; indeed, electronics serve as the basis for many of the aforementioned models used throughout the piece. As a model for the vocal writing for example, Leroux requested that the vocalist record improvisational sequences using certain extended techniques. Sounds from these recording were then cropped and rearranged (using simple editing techniques) in order to construct new sounds that the vocalist was then to imitate. This process of creation, modification and remodelling was repeated several times, allowing the composer to collect a wide variety of unusual vocal components, which would later serve as models for instrumental and electronic writing. Likewise, the harmonic language of the piece was modelled on recordings of the vocalist speaking the text in great proximity to a tam-tam. The resonance of the tam-tam, excited by the vocalist's voice, was then analysed in order to identify and extract harmonic elements, which were then used throughout the piece.

As with electronics, Leroux employed the text in a thoroughly integral manner, using it both as a source of sound material and structural organisation. Locally, phonetic aspects of the text are regularly employed as elements of vocal writing (Ex. 1). Furthermore, calligraphic elements of the text are used as visual elements throughout the piece: the vocalist "writes" verses of the poem in the air, her gestures synchronised with electronic sounds that correspond to the contour of the letters (Ex. 2). This visual aspect of the text is further exploited on a structural level: the contour of the letters serve as melodic profiles, characterising the melodic vocal part that appears in certain movements and contrasting with the more ephemeral and noisy as well as longer and harmonic elements that qualify other sections of the work. Moreover, the calligraphic contour also dictates the movement of sound throughout the hall (Ex. 2b). Beyond the visual and audio qualities of the text, its semantical meaning bears a strong influence on the texture, atmosphere and general character of each movement as well.

The precise and highly analytical approach to both sound and text is characteristic of works composed at IRCAM. *Voi(Rex)* corresponds to the institute's aesthetic approach to electronics which leaves little up to error or chance, thus simplifying the reproduction of the piece in future performances in a manner as loyal to the original as possible.



Ex. 1 : Phonetic elements in vocal writing



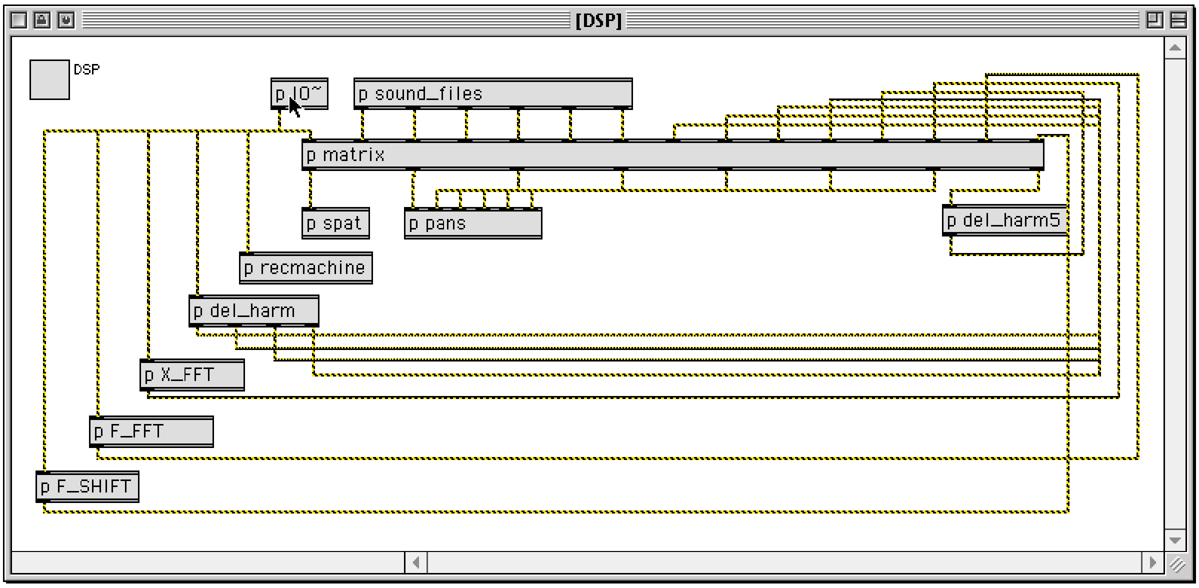
Ex. 2a : Vocalist "draws" a comma while making a blowing sound

II.1.2 Electronics

The live-electronics in *Voi(Rex)* comprise both sound files triggered at distinct points throughout the work and real-time treatment of the voice. Additionally, the vocalist and ensemble are amplified in order to better blend with the electronics, and a meticulously planned spatialisation scheme is applied.

All sound files and treatments are triggered by the vocalist herself using a MIDI triggering device, which communicates with a Max/MSP patch in order to assure that the electronics be synchronised as closely as possible with the voice[1]. The patch carries out the playing of the sound files as well as the operation of the treatments and spatialisation (Ex. 3). The sound engineer is simply entrusted with the task of managing the balance between the amplified direct sound and the electronics, and verifying that the patch functions correctly.

[1] Nevertheless, in many performances of the work, the sound engineer or an additional electronics player triggers the sound files and treatments directly from the computer

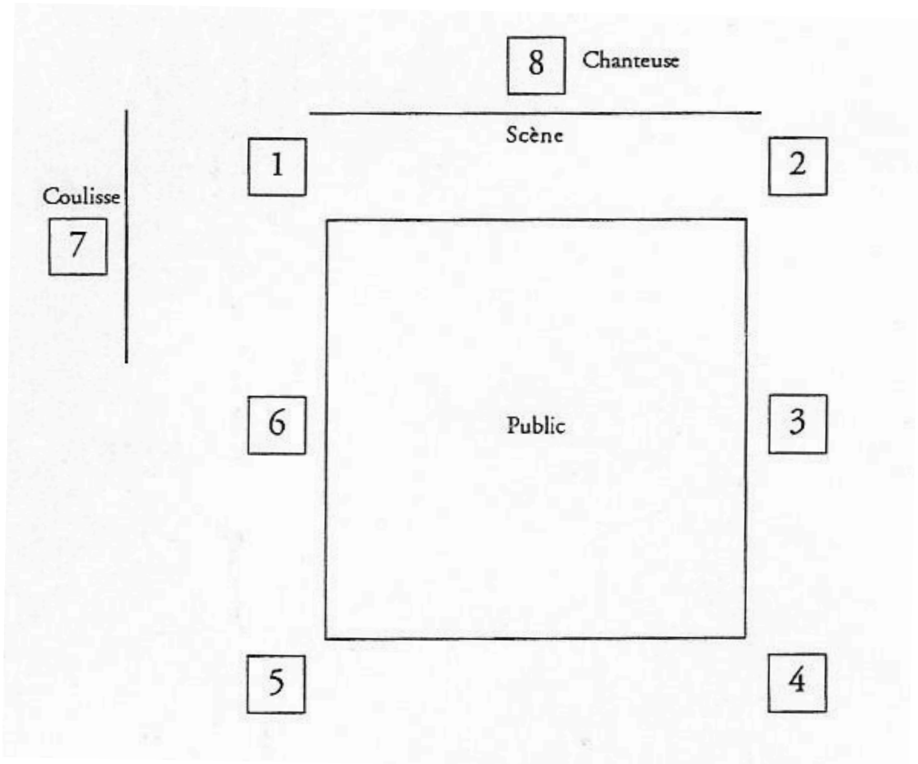


Ex. 3 : the *Voi(Rex)* patch controls the playing of the sound files and processing of live treatments

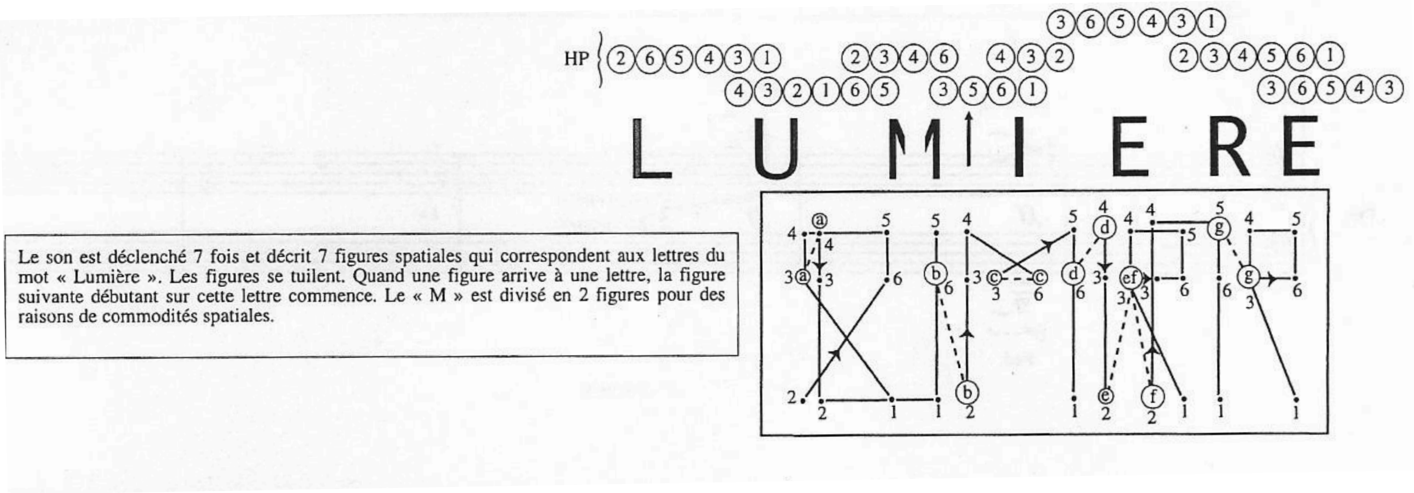
Three main elements are regulated by the patch:

- Sound files – *Voi(Rex)* makes use of one hundred and nine sound files of varying lengths, composed from edited and treated recordings of the vocalist and instrumentalists stored as buffers in the patch. These may function as independent sound elements, providing a counterpoint or development of the vocal part, or as colour elements, orchestrating or punctuating the vocal part. In both cases, the files are precisely measured as their effectiveness depends largely on their coincidence with instrumental or vocal events.
- Real-time treatments – solely the voice is manipulated in real-time, using the following effects: delay, harmoniser, filtering, reverb, frequency shifting, looping and cross synthesis. Generally, the voice is recorded into a buffer in real-time and then treated. The parameters of the treatments are defined in the patch and triggered by the vocalist. Though most of these treatments represent on-going transformations and not discrete events, their use is generally confined to a pre-defined time period and limited dynamic, and are synchronised with other musical events. As such, they may be heard as colours, an electronic orchestration of the voice, rather than as processes or independent sound objects.

- Spatialisation – *Voi(Rex)* was intended to be performed using eight loudspeakers – a circle of six loudspeakers around the audience, one on stage behind the vocalist, and an additional loudspeaker off-stage (Ex. 4). Nevertheless, Leroux indicates that the piece may be performed with solely two loudspeakers if necessary. As with the other electronic elements, the displacement of sound throughout the hall is comprehensively conceived: at times, the spatialisation is used to differentiate between various components of the electronics and the amplified voice/ensemble, at others it underscores delicate textures with its subtlety or reinforces dense moments with its presence. Furthermore, the sound follows a spatial path that mimics the calligraphic contour of the text as well as the visual gestures performed by the vocalist in specific instances (Ex. 5). Nevertheless, Leroux does not use space as a motivic element in and of itself, nor does the spatialisation play an important formal role. As such, it remains a secondary constituent qualified by its relationship to the vocal/instrumental writing and sound files.



Ex. 4 : The spatial set-up of *Voi(Rex)*



Ex. 5 : Seven sounds are played and spatialised according to the shapes of the letters

Clearly, the many electronic elements present in both the final version and intermediary stages of *Voi(Rex)*, were thoroughly thought out and meticulously realised by both the composer and his supporting team at IRCAM. The essence of the electronics is based on sound and colour rather than process and transformation. As a result, the piece combines voice, instruments, gesture and electronics in a punctilious and integral manner that can easily be repeated in performance, but which leaves little room for improvisation or interpretational variations.

II.1.3. Notation

In the majority of Leroux's oeuvre, electronics play an essential role from the very onset of the compositional process through the realisation of the piece. As such, the frequently encountered two-step composition process – first the instrumental score is composed and printed, and only thereafter are the electronics accounted for – is avoided, and the electronics are comprehensively represented in the final score. Leroux's compositional approach, which allows for such highly reliable electronics, requires great control over their temporal aspects; thus their conception is similar to that of traditional instrumental writing, in which musical events can be linearly envisaged as discrete instances on a Cartesian axis. Consequently, the score to *Voi(Rex)* provides thorough documentation of the electronics without greatly deviating from traditional musical notation.

In *Voi(Rex)*, the composer employs several staves in order to represent multiple aspects of the live-electronics, which are classified as follows in this analysis:

- Cue staff – a five-line staff directly beneath the voice staff indicating the cues and nature of the events to be triggered by the vocalist (bracketed with the voice staff).
- Pitch-rhythm-dynamics (PRD) staff – a five-line staff indicating the pitch, rhythm and dynamics of the sound files and real-time treatments. At times an additional staff is appended for this purpose (bracketed with the two following electronics staves) (Ex. 7).
- Morphology staff – a five-line staff on which appear graphical descriptions of the sound files and treatments following Schaefferian principals of typo-morphology[2] (bracketed with the PRD staff and the following electronics staff) (Ex. 8).
- Spatialisation staff – a lineless staff indicating the number(s) of the loudspeakers employed and the movements between them (bracketed with the two previous electronics staves) (Ex. 9).

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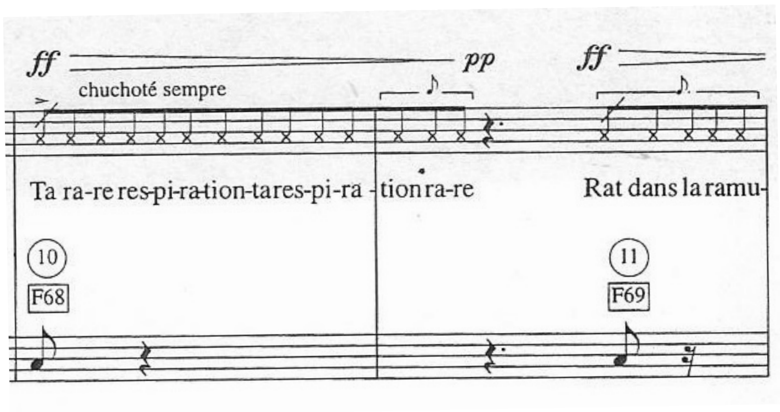
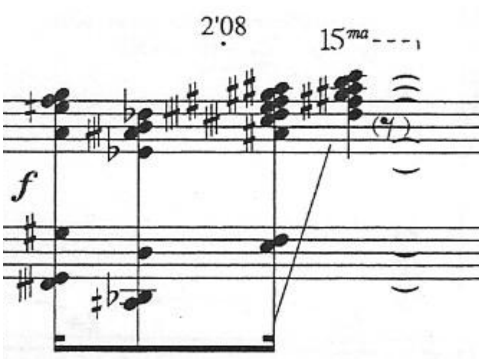
[2] analytical approach to acousmatic music introduce by Pierre Schaeffer in *Traité des Objets Musicaux* (1966). The approach has three steps: identifying sounds, classifying them according to typological terms, then describing them according to morphological terms.

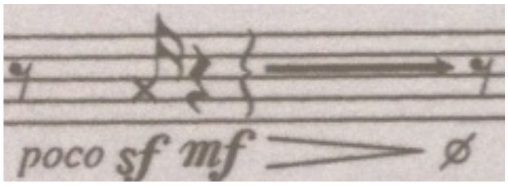
On the cue staff, each cue is indicated by a sixteenth or eighth note in the space corresponding to a^1 (treble clef) at a precise rhythmic position (Ex 6.). Occasionally, when a cue triggers two different types of events, an additional notehead appears on the line corresponding to e^1 (treble clef). This information is naturally prescriptive in nature, as it instructs the vocalist when to perform a gesture which is then translated into a sound result, yet does not indicate the sound result itself. Nevertheless, the cue staff also contains information of more descriptive qualities: when a cue triggers a sound file, the filename is indicated as boxed text above or below the corresponding notehead; when a cue triggers the beginning or end of the real-time recording process, the text "R. on" or "R. off" appears above the notehead.

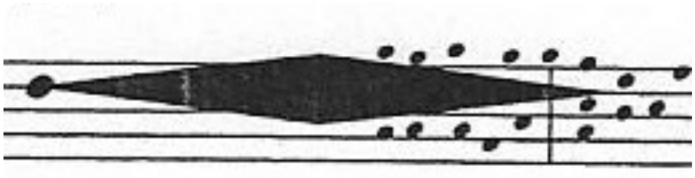


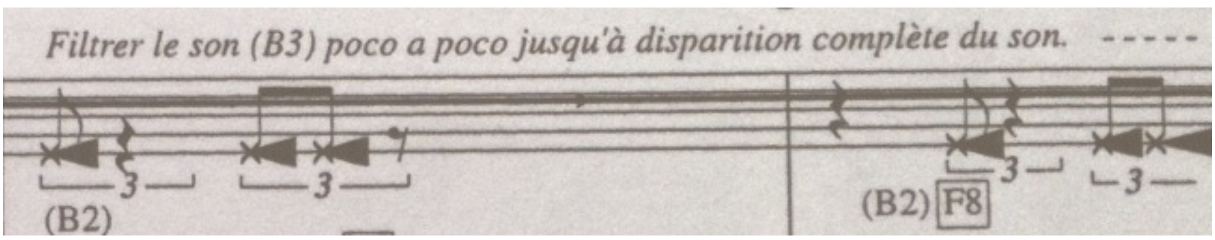
Ex. 6 : The top staff shows the vocal part while the bottom staff indicates the triggers and the corresonding sound files

The PRD and morphology staves both serve a mainly descriptive role. Though the two staves generally complement each other throughout the piece, the attribution of descriptions of sound elements to one staff or another are at times questionable. The PRD staff is notated in treble clef and makes use of both traditional notation and simple graphics. The staff indicates any pitch-related details using standard notes (Ex. 7a), thus providing an accurate description of the copious pitch material present in the electronics with great rhythmic precision. In addition to noteheads and rhythms, some basic graphics – also very traditional in contemporary music – are employed: bold horizontal lines, both straight and sinuous, are used to indicate the prolongation of a treatment, sound file or pitch group, or to denote the vibrato-like character of an undulating sound (Ex.7b); expanding and contracting hairpin-forms (as those of a crescendo or decrescendo), both opaque and clear, are used beneath the staff to depict the dynamic profile of a sound or treatment, and on the staff to describe a change in both its dynamic profile and ambitus (Ex.7c).









Ex. 7 : Elements notated on the PRD staff : a) pure pitch material (above left) ; b) prolongation line (above right) ; c) indication of dynamic profile and ambitus (middle) ; d) "B" numbers indicate portions of the vocal part that have been recorded, while their treatment is shown by the italicised text (below)

Beyond the on-staff descriptions, the PRD staff provides extremely relevant textual descriptions of real-time treatments. The type of treatment as well as its principal parameters appear as italicised text above the staff. Furthermore, numbers with the prefix "B" denoting specific segments of the real-time recorded voice part appear atop the PRD staff to indicate when these recording are either played back or treated. The same boxed numbers can be found above the main vocal staff and therefore provide a valuable cross reference (Ex. 7d).

The morphology staff, while intended for graphic descriptions of the sound material that cannot easily be quantified in units of pitch or rhythm, is somewhat inconsistent and regularly disappears from the score. At times, graphic information seemingly appropriate to this staff is indicated on an expanded PRD staff instead, and at times textual details of real-time treatments appropriate to the PRD staff appear as morphological descriptions. Consequently, this staff functions principally as a supplement to the information already present in the PRD staff.

The graphic indications on the morphology staff are limited to lines and blocks of varying thickness and contour. The vertical position of the graphics and their variation along the y-axis correspond to melodic profiles while their thickness and opaqueness represent the mass profiles[3] (Ex. 8).

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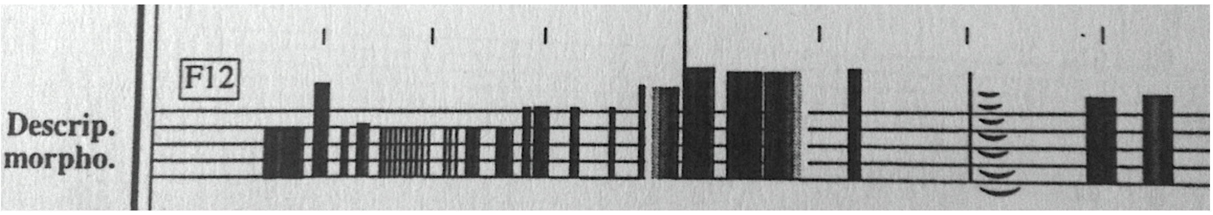
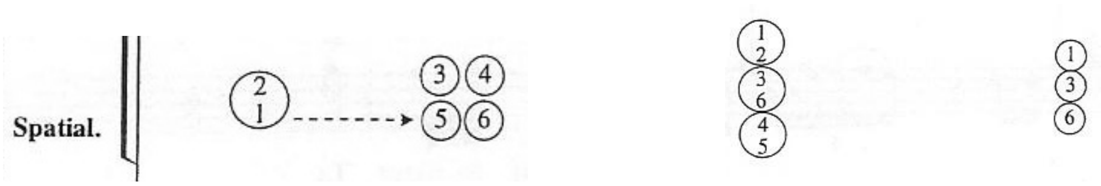
[3] *Melodic profile* – the trajectory of a sound object through pitch space. *Mass profile* – the variations (or sculpting) of the internal mass of a sound. Both terms were invented and defined by Pierre Schaeffer's morphology.



Ex. 8 : The morphology staff uses blocks and lines of different thickness to indicate melodic and mass profiles

Finally, the spatialisation staff indicates the spatial position of the sound in the hall using circled digits corresponding to the eight loudspeakers described above. The treatment, sound file, or amplified sound to be diffused is noted next to each loudspeaker circle in the score. Transitions from one or more loudspeakers to other loudspeakers are notated using dotted arrows (Ex. 9). This method is straightforward and therefore requires no further explanation.



Ex. 9 : The spatialisation staff

II.1.4. Benefits and Shortcomings

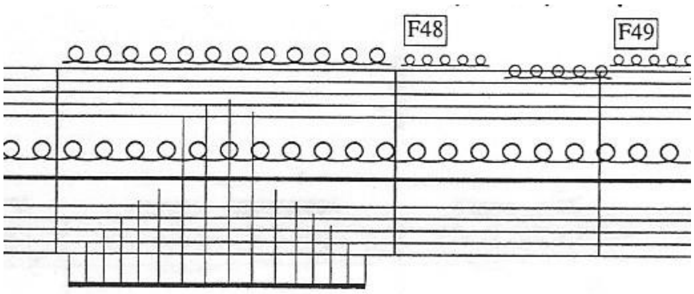
In a work in which the role of the sound engineer is intended to be rather limited, prescriptive instructions are not entirely necessary. This justifies Leroux's use of largely descriptive notation for the electronics staves, while the prescriptive indications are limited to the vocal part.

Nevertheless, due to variations in hall acoustics and material in many performances of *Voi(Rex)*, the sound engineer is required to meddle more seriously in the electronics and balance the various treatments and sound files. In this case, the sound engineer must closely follow the notation in order both to ensure that the cues are properly triggered and in order to properly balance the electronics with the voice. In such a case, the largely descriptive notations have a prescriptive quality concerning dynamics, as they dictate how to mix the treatments. The internal dynamics of the sound files obviously cannot be controlled, and therefore their notation remains purely descriptive.

Cue staff – the notation of cues is rather felicitous as its simplicity renders it accessible and easily legible upon a first reading. Additionally, the proximity of the cue staff to the vocal staff allows the vocalist to clearly see the rhythmic positioning of the cues in relation to her part. However, the additional indications appearing on the staff are less practical for the performer: they provide information that is neither relevant to the vocalist, nor easily integrated upon a first reading (for example, the boxed text "F16 bis" does not translate to an action or musical idea to anyone unfamiliar with the patch and sound files). Notwithstanding, this information serves as an invaluable cross reference for the indications given on the remaining electronics staves, should the sound engineers be required to play a larger role than intended in the performance.

PRD staff – this staff allows the sound engineer to follow the electronics and react if required. The use of a five-line staff to reflect a material of definite pitch and rhythm is clearly appropriate; as such, it acts as an additional instrumental staff. Additionally, the indication of sound file names and of the sections of the vocal part that are recorded and treated is useful for assuring that the patch functions as intended as the sound result is easily understood. The textual explanations of the real-time treatments used and their main parameters are similarly helpful. Thus, the PRD staff is an exhaustive representation of the majority of the characteristics of the electronics.

While this notation has many advantages, it also has several drawbacks. The enormous amount of information that appears on the staff lends itself neither to quick reading nor to quick reaction; the sound engineer must learn this staff well in advance in order to fully respond to the many indications. It would perhaps be useful to distribute this information over two staves: one which is more pertinent to the live performance and another which supplies the additional information that is less relevant in real-time. Another drawback is the ambiguity of the graphics appearing on this staff. While the images used seem to follow Schaefferian morphological descriptions, it is still nearly impossible to know or imagine which sound they allude to (Ex. 10). This is a general issue when "drawing" sounds, as there are as many graphics systems as composers, even when they share a philosophical or semiotic basis.



Ex. 10 : ambiguous graphic descriptions

Morphology staff – as with the PRD staff, this staff has very limited prescriptive use. It serves primarily as a means of following the sounds that cannot be described using pitch, rhythm or dynamics. Beyond the previously mentioned issue, that the distribution of sounds between this staff and the PRD staff is not entirely evident, the morphology staff suffers from the same graphic ambiguities as the its neighbouring staff. As such, this staff functions more as a somewhat poetic, individual supplement to the information presented elsewhere in the score than as useful indications for the performance. It would perhaps be more logical to redistribute the information on both the PRD and morphology staves in a manner that hierarchises the many details so that those more immediately necessary for performance are more easily accessible.

Spatialisation staff – this notation is so simple and clear that its presence can only contribute to the understanding of the electronics. If the sound engineer is not required to adjust the spatialisation, the information on this staff serves as another means of following the progression of the score; if due to acoustics the engineer must reinforce the spatialisation, the notation serves as prescriptive indications.

The notation in *Voi(Rex)* is perhaps superfluous. Nevertheless, in a world in which notation of electronics is frequently neglected, excessive detail is a lesser evil. It would however behove the composer to streamline the presentation of the information provided so that it may be more quickly and immediately integrated by the relevant performers.

II.2. *MIXTUR* – KARLHEINZ STOCKHAUSEN

II.2.1. Background

In the early 1960's, as live electronics were slowly being introduced into the contemporary music world, Karlheinz Stockhausen was actively pioneering new methods of integrating electronics in live acoustic performances. After having composed *Kontakte* (1959-60), in which a pre-recorded tape is diffused on loudspeakers while a pianist and percussionist play their respective parts, Stockhausen sought to combine live performance and electronics in a more flexible manner. The research that ensued gave birth to *Mikrophonie I*, one of Stockhausen's token works: two players use various materials to make a gong resonate while two other players move microphones in proximity to the gong and two additional players alter the sound using filters. Following the success of *Mikrophonie I*, the composer wished to apply live electronics to a full orchestra. Thus, *Mixtur* became one of the first pieces in which an orchestra is electronically transformed in real time.

Mixtur was composed for five orchestral groups: woodwinds, brass, pizzicato strings, bowed strings and three percussionists each playing a cymbal and a tam-tam. The players of each group are seated together separately from the other groups, either on stage or distributed throughout the hall. The sound of each group is modulated with four sine waves; the four modulated signals are then amplified respectively on four loudspeakers (or sets of loudspeakers). While the sound of the three percussionists is not modulated, it is amplified directly on three loudspeakers using contact microphones placed on the instruments. (See further explanations about the electronics in section II.2.2). Since the direct and modulated sound inhabit the same space, the relationship between the inputs and outputs as well as their dynamic dependence are emphasised.

Formally, *Mixtur* is a *moment form*[4] comprising twenty movements, or *moments*, which can be played in written order, backwards, or in yet other orders permitted by the composer (Ex. 11). As with the implementation of live electronics in performance, Stockhausen first developed the idea of a moment form in *Kontakte*. The composer

4

defines his newly coined term *moment* as a "formal unit in a particular composition that is recognizable by a personal and unmistakable character… Depending on their characteristics, they can be as long or as short as you like." Each of the twenty moments of *Mixtur* bears a distinct and timbrally characteristic title and is given a duration in units whose tempo may vary from 40 to 60 bpm (Ex. 12). The precise tempo is to be determined by the conductor before each performance and must remain consistent throughout the piece; therefore, the proportions between the movements are pre-determined but not their absolute durations. In addition to these timbral and temporal properties, many of the moments can also be qualified by the central tone(s) around which they are constructed (Ex. 13).

MIXTUR und WECHSEL sind vertauschbar.

SPIEGEL und STUFEN sind vertauschbar; bei Vertauschung soll so viel Rubato in STUFEN gemacht

BLECH und KAMMERTON können gleichzeitig anstelle von WECHSEL gespielt werden; sow

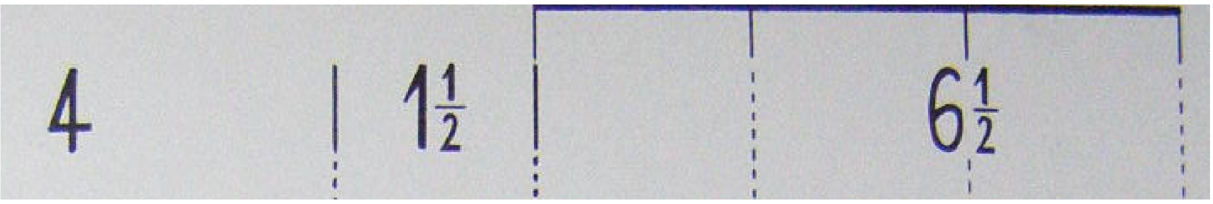
dann der erste Takt 10, und der erste Blechakkord in KAMMERTON fällt weg. Anstelle von BLECH

gespielt, und zwar ohne den 2. 6. und 12. Takt. Anschließend wird WECHSEL ohne Blechbläser wiede

ten die Pizzicato-Instrumente die Töne im 3. und 7. Takt bis zum folgenden Takt mit schnellen Repetiti

Entweder BLÖCKE und KAMMERTON oder KAMMERTON und HOHES C sind vertauschbar.

Ex. 11 : Excerpt from the composer's indication concerning the order in which the moments are to be performed



Ex. 12 : Temporal units indicating the relative length of each section

	name	central tone(s)	omitted tone(s)	duration	rest (proportion)
1	Mixtur [mixture]	C_7	F♯	12	0
2	Schlagzeug [percussion]	—	—	30	1/5
3	Blöcke [blocks]	B_5	F	78	1/2
4	Richtung [direction]	$C\sharp_6$	G	48	1/3
5	Wechsel [exchange]	$A\sharp_6$	E	18	1/6
6	Ruhe [quiet]	D_5	G♯	78	0
7	Vertikal [vertical]	A_4	D♯	12	1/6
8	Streicher [bowed strings]	$D\sharp_4$	A	18	1/5
9	Punkte [points]	$G\sharp_5$–E_3	D–A♯	30	1/3

Ex. 13 : Table indicating the central tone, duration and proportion of the first nine moments of *Mixtur*

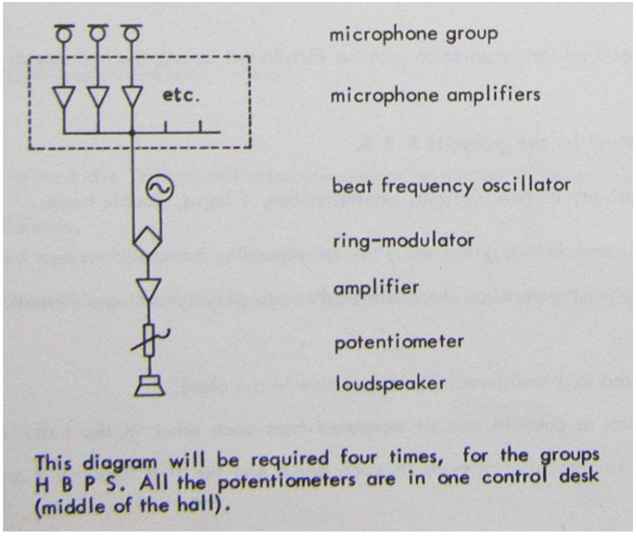
In creating one of the first live-electronic orchestral works, Stockhausen opened a door to many new compositional and sound possibilities that were heretofore unimaginable. The use of live ring modulation not only allowed him to create new timbral combinations but also to generate pitch variations independent of the division of the octave into twelve semitones (or twenty-four quartertones). Likewise, the use of sine wave oscillators below a frequency of sixteen Hz engendered new and interesting rhythmic transformation of the instrumental sounds. Finally, the unexpected relationship between the direct instrumental sound and the treated sound explored the possibilities inherent to non-linear interactive schemes which would contribute greatly to the evolution of interaction in future live-electronic works.

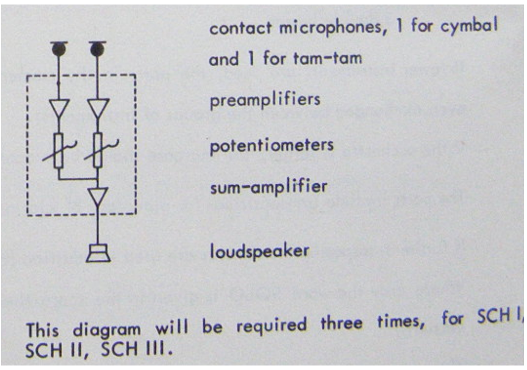
II.2.2. Electronics

The performance of *Mixtur* necessitates the use of the following equipment:

- Contact microphones to be placed on the instruments of the three percussionists.
- Aerial microphones to pick up the sound generated by the four orchestral groups. Stockhausen indicates neither how many microphones are to be used, nor where they are to be positioned; nevertheless, it is clear that in order to bring out the diverse orchestral textures appearing in the score, a great degree of control is required over the balance within each group. Thus, in most performances of the work, each instrument is microphoned individually.
- Four sine wave oscillators to produce a signal to be multiplied with the sound of each orchestral group.
- Four ring modulators to multiply the two aforementioned signals.
- Five loudspeakers (or sets of loudspeakers) to amplify the output of the ring modulators and the percussion. Each loudspeaker is positioned in close proximity to its respective instrumental group so that the electronic treatment of each group can be spatially associated with its direct sound source.

The interaction between the different sound producing and sound modifying constituents mentioned above can be described by the following scheme (Ex. 14):



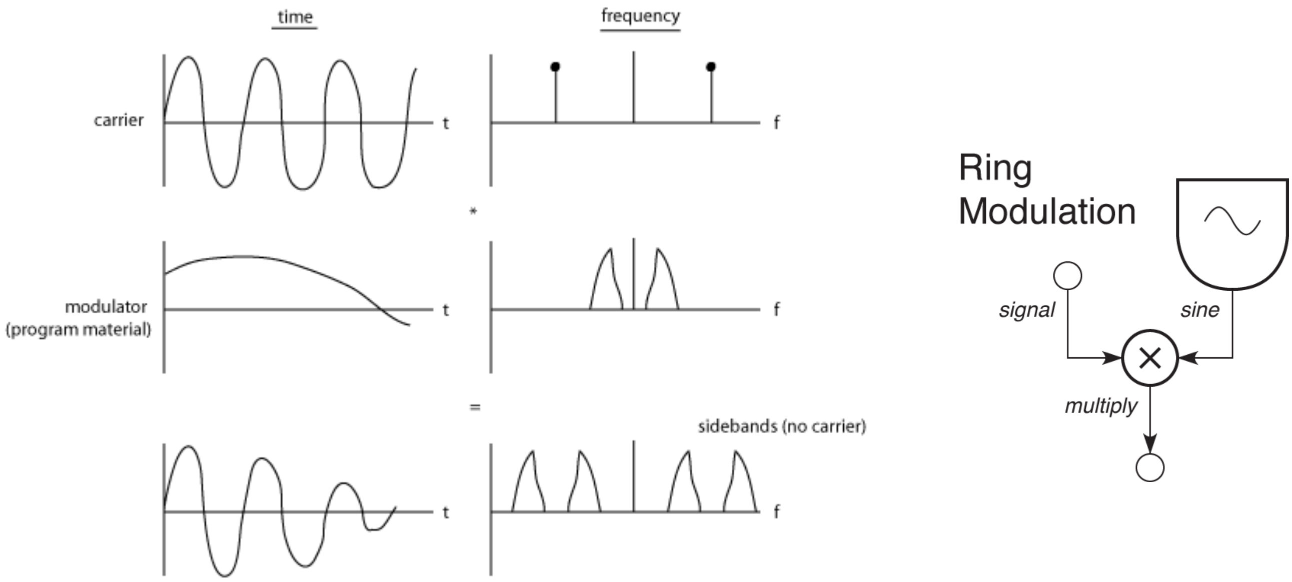


Ex. 14 : technical set-up scheme

The implementation of this scheme in *Mixtur* requires three fundamental live-electronic manipulations :

- Pre-mixing – the sound of each instrumental group is balanced in real time by a sound engineer before being sent to the ring modulator, in order to bring out certain timbres.
- Ring modulations – the sound of each group is modulated by a sine wave oscillator, operated by another musician.
- Post-mixing – the outputs of the ring modulator and of the three amplified percussionists are balanced in the hall (without being mixed further).

Of these three, ring modulation is the principal, most characteristic and most-sound altering operation. Ring modulation is a signal processing function performed by multiplying two waveforms referred to as *carrier* and *modulator* signals, of which the carrier is generally a sine wave or another simple function. This multiplication results in two sidebands corresponding to the sum and difference of the frequencies contained in the two multiplied waveforms; the carrier frequency is not present in this new spectrum (Ex. 15). For example, if a sine wave of a frequency of 440 Hz (a') were modulated with a sine wave of a frequency of 660 Hz (e'', a perfect fifth above), a tone at 1100 Hz (c#''') and a tone at 220 Hz (a) would be produced. Since the modulator signal is generally non-sinusoidal and contains many partials in addition to its fundamental tone, the modulation process produces a complex signal containing copious sum and difference tones. If the modulator signal is harmonic, the resulting spectrum will have much in common with the original spectrum allowing the construction of harmonic structures; if however the modulator signal is inharmonic, the ring modulation will produce a spectrum of greater inharmonicity characterised by a metallic or bell-like timbre. Since in *Mixtur* the modulator signal comprises the many timbres of an entire instrument group, the modulation engenders a rich, unique and rather unpredictable sound world.



Ex. 15 : signal and sidebands produced by a ring modulation (left) ; the multiplication of a carrier and modulator signal to forma ring modulation (right)

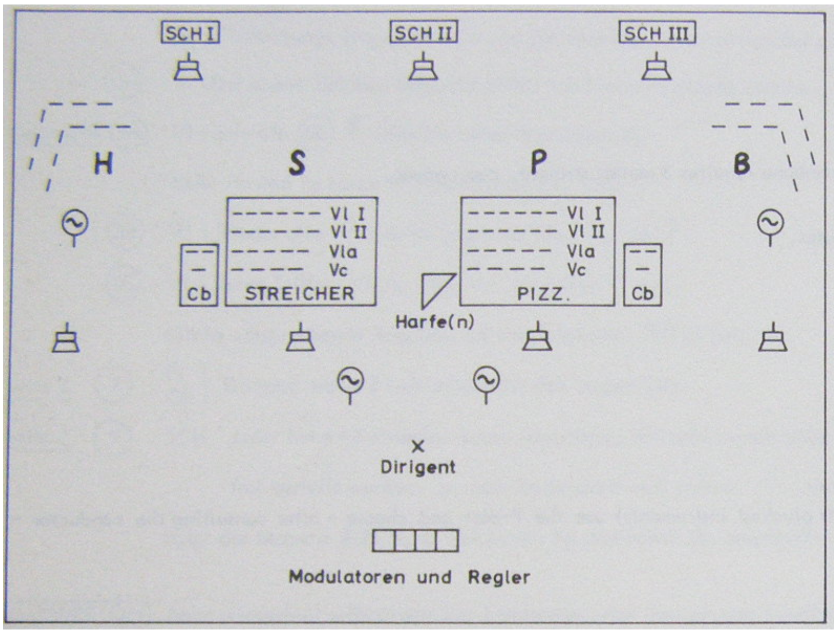
The ring modulation is made possible by the four carrier signals, generated by four sine wave oscillators, which are operated at different frequencies by musicians or sound engineers. These four performers, who are given specific instructions in the score (see II.3.3) as to which frequencies they are to produce, play a particularly important role in the composition as they modify the orchestral input in a multitude of ways resulting in a wide variety of output signals.

No less musically important is the premixing process, which controls the balance within each orchestral group and therefore determines the timbral and dynamic properties of the modulator waveform. In many sections of *Mixtur* it is understood from the dynamic notation[5] that certain instrumental sounds are to be heard more or less than others; it is the task of the premixers to ensure that this is achieved. Additionally, in recent decades *Mixtur* is performed using digital rather than analogue ring modulators, which can easily produce unwanted distortion noises when overloaded. Consequently, the pre-mixers must manage the final output gain of their mixes (directly before the signal is input into the ring modulator) with great sensibility to assure that these noises

[5] All dynamics are sounding dynamics

are not generated. Thus, the pre-mixers play an invaluable role in the interpretation of *Mixtur*.

After the sound has been premixed and modulated, the sound engineer charged with post-mixing must manage the overall balance between the five groups as well as the balance between direct and modulated sound. *Mixtur* is unlike other multiphonic live-electronic works in which the sound engineer has some control of the panning of the sound in the hall. Here, the loudspeakers are placed directly above the orchestral groups (which may be distributed on stage or in a circle around the audience), therefore the modulated sound of each group remains associated with a specific area of the hall throughout the piece and cannot be panned (Ex. 16). Nevertheless, the post-mixing sound engineer may create the impression of a dynamic spatialisation by managing the volume of each group in such a way that alternations and transitions from one orchestral group (in one region of the hall) to another (in another region of the hall) are produced.



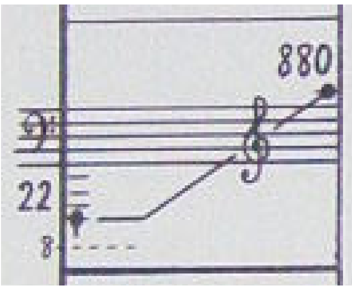
Ex. 16 : Stockhausen's diagram showing the positioning of the loudspeakers in proximity to the orchestral groups

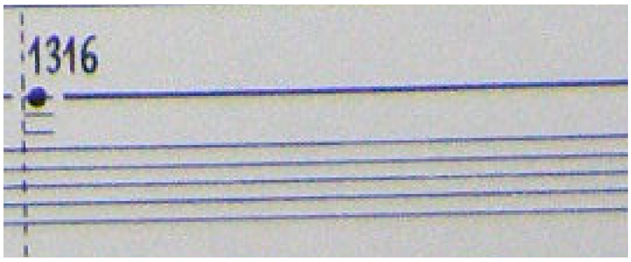
II.2.3. Notation

The score of *Mixtur* begins with lengthy and thorough instructions explaining the technical set up of the work and the desired sound result. These instructions do not contain very specific technical details, such as the exact number and type of microphones and loudspeakers to be used; instead, they present a simple explanation of the set-up and the aesthetic desires of the composer.

Of the three electronic manipulations mentioned in the previous section, only the operation of the sine wave oscillators is accounted for in the score. The pre-mixers and post-mixers must extrapolate their roles from the instrumental writing.

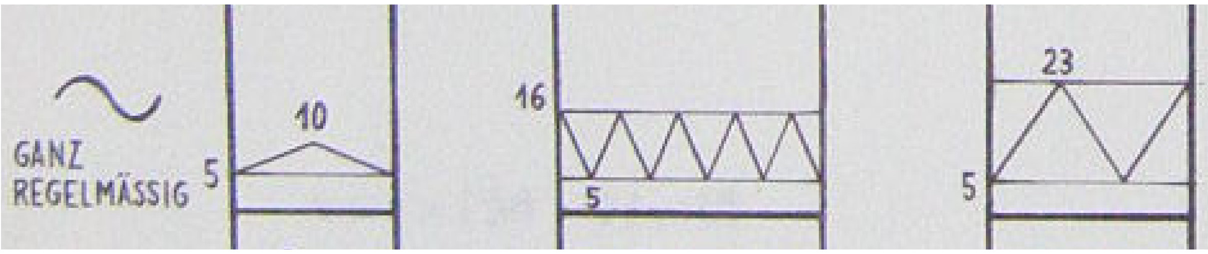
The sine wave oscillators are generally notated on a regular five-line staff in treble or bass clef; when operated at frequencies below 50 Hz they are notated on a lineless staff, as this register is characterised by its rhythmic rather than pitch characteristics (Ex. 18). On five-line staves, pitches to be attained by the oscillators are indicated as stemless noteheads, with the frequency in Hertz indicated above or below[6]. Transitions from one frequency to another are indicated with diagonal lines connecting the two frequencies while the prolongation of a frequency is indicated with a horizontal line (Ex. 17).





Ex. 17 : Sine oscillator staff : glissando between two frequencies (left) ; a prolonged frequency (right)

[6] Often, the frequencies indicated do not accurately correspond to the pitch indicated by the notehead. These are unlikely to be errors; Stockhausen may have intended the inaccuracies in order to create a variety of acoustic phenomena, such as beating.

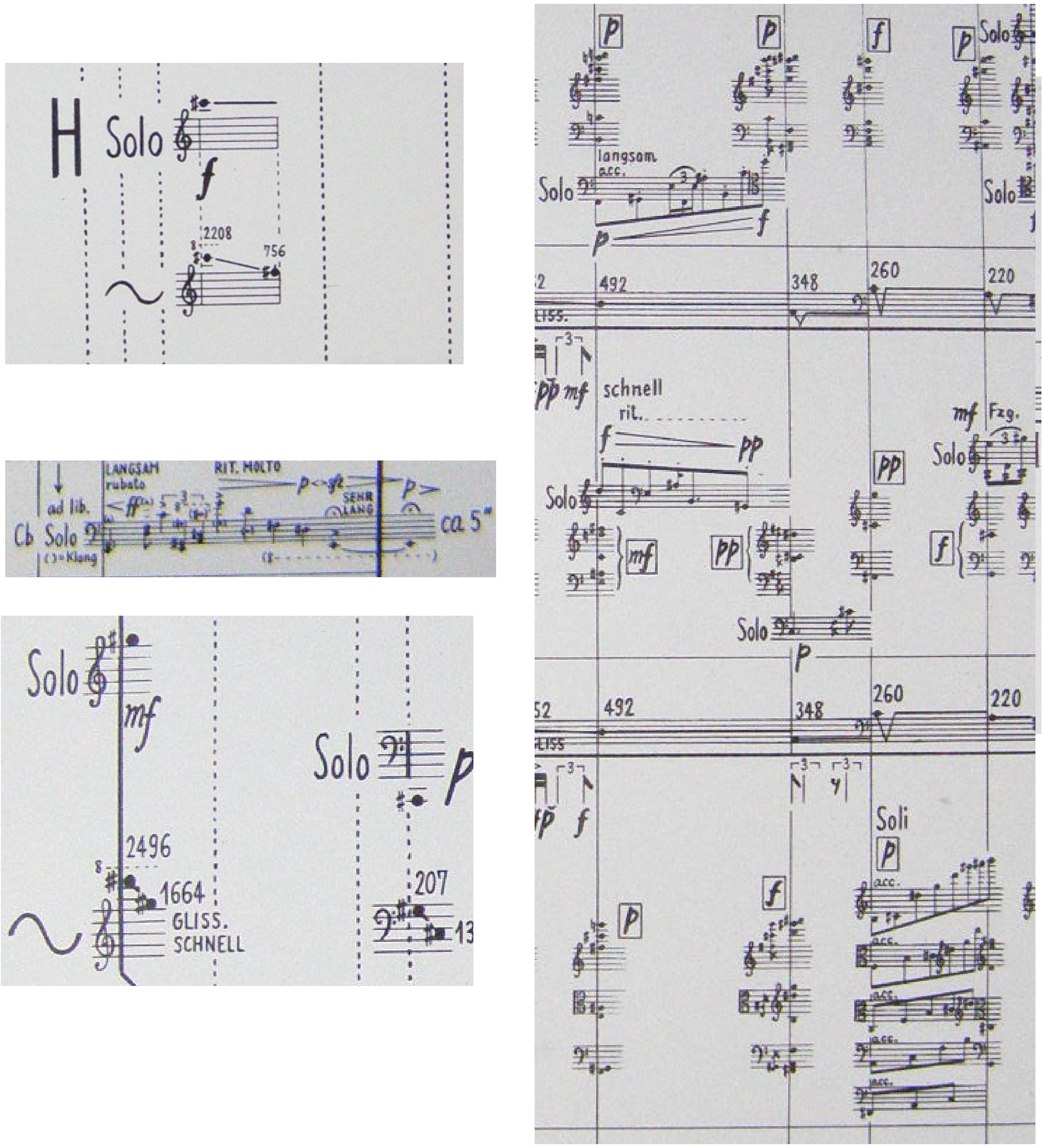


Ex. 18 : sine oscillator staff for frequencies beneath 50 Hz.

As with the instrumental parts, the gestures of the sine wave oscillators are measured in units between forty and sixty bpm, as determined in the beginning of the performance. These units are notated proportionally on the temporal axis; thus, the rate of frequency transitions performed by the oscillator players can be rather intuitively understood from the score. Stockhausen provides no dynamic indications for the sine wave oscillators as this parameter is dependent upon the dynamic of the modulator signal and is not directly controlled by the players. Therefore, the dynamics are regulated by the pre-mixers.

As previously mentioned, no indications are given concerning the pre-mixing and post-mixing process. However, certain details can be deduced from the notation of the remaining instruments. In the movement *Richtung* for example, the woodwinds only play intermittent soli passages. It is therefore clear that the pre-mixer should only send the signal of the solo instruments to the ring modulator, and only at the very moment in which the soli are played (Ex. 19a). Otherwise, the ring modulator is likely to generate unwanted noises, even when the other instruments do not play. Likewise, the contrabass solo in the end of *Spiegel* must be brought out in comparison to the remainder of the bowed string group (Ex. 19b).

The post-mixer must can also extrapolate playing instructions from the general and instrumental dynamics. Thus, in movements such as *Wechsel*, in which solos alternate between the four orchestral groups, it is the post-mixer's task to assure that the treatment of the group containing a solo passage is more prominently heard than those of the other groups (Ex. 19d). Similarly, in *Punkte*, it can be understood from Stockhausen's indications "alle Töne sehr kurz" and from the empty space left between musical events, that the post-mixer should shut off the modulated signal after each event is played in order to preserve the short, disparate and pointillist character of the music (Ex. 19c).



Ex. 19 : Passages that must be carefully pre- and post-mixed : a) wind solos in *Richtung* (left above); b) contrabass solo in *Spiegel* (left middle); c) short, pointillistic events in *Punkte* (left bottom); d) alternating solo passages in *Wechsel* (right)

II.2.4. Benefits and Shortcomings

Technical indications in the beginning of the score – as the composer's intention is clear, the sound engineer may approach his assignment with greater clarity and freedom, choosing to reproduce the composer's sound world with the means that he deems most appropriate. Furthermore, Stockhausen leaves room for variation of some aspects of the electronics (for example, the positioning of the orchestra and loudspeakers), fixing only those details that are indispensible (for example, the lack of amplification of the direct orchestral sound). Thus, these instructions clarify both the technical necessities of the piece and the composer's attitude toward the interpretation. These indications allow the piece to be reproduced more easily while respecting the Stockhausen's artistic vision.

Sine wave oscillator staves – the principal parameters of the oscillators are pitch and time, both of which lend themselves well to the standard staff notation in which time is represented on the x-axis and pitch on the y-axis. As such, Stockhausen's notation benefits to a certain extent from standard notation's ability to be both prescriptive and descriptive: it indicates to the players both what they are to do (tune the oscillator to a given frequency at a given point in time) and the sound result of their actions (the pitch produced). These are of course only partial prescriptions and descriptions. The prescriptive instructions are not associated with the players' gestures (as would be the case in standard notation): the performer may move a fader, a knob, push a button, or carry out any other number of gestures, depending on the oscillator used. None of these gestures are indicated in the score. Likewise, the descriptive aspects of the notation only apply to the (approximate) pitch produced by the oscillator but does not represent the many transformations that result from the ring modulation.

The use of five-line staves and proportional temporal notation is thus rather pragmatic and allows for the piece to be reproduced using any variety of oscillators; however, it does not accurately represent the desired sound result. It would perhaps be useful for the oscillator players to know that a beating effect, a harmonic or inharmonic sound, or a resonance phenomenon is to be produced in certain sections. With this knowledge, they could be assured that they are indeed performing their tasks correctly, and could further underscore the desired effect.

The one-line staff used for the oscillators operating at inaudibly low frequencies is also a felicitous choice, as it clearly distinguishes the roll of the oscillator as a rhythm-controlling device rather than a pitch-controlling one. As with the other oscillator notation, the actions to be performed by the players are easily understood. Though the y-axis can no longer be directly associated with pitch, the relationship between the vertical position on the staff and the frequency is still very intuitive. This representation is however not convey the sound result of the transformation. It would perhaps be useful to include some indication of the rhythmic transformations produced as a result of the oscillators. The correlation between the augmentation or diminution of the frequency and the speed of the rhythmic variation would serve as a useful aid for the operators of the oscillators.

Pre-mixing and post-mixing – the lack of indications concerning these two roles is perhaps due to the fact that many of their demands were first determined in rehearsal, when the need arose to control the chaotic nature of the player-treatment interaction. Furthermore, since the tasks of the mixers are entirely dynamic-based, they may vary immensely as a function of hall acoustics and material used, and therefore may not greatly benefit from a precise notation.

Notwithstanding, it is evident that some indications are necessary for the successful future performances of *Mixtur*, as at present, the instructions for these extremely significant roles are passed down orally. Any notation of these tasks should indicate: when to shut off the output gain (of one or more instruments/groups), when to emphasise the spatial positioning of the groups through mixing, which instruments to bring out in complex textures within a group, which group to bring out in complex multi-group textures, among others. These basic indications are indispensible when performing *Mixtur*.

II.3. *HYPERMUSIC PROLOGUE* – HÈCTOR PARRA

II.3.1. Background

Hector Parra's opera, *Hypermusic Prologue, a Projetive Opera in Seven Planes*, was commissioned by IRCAM and the Ensemble Intercontemporain, and premiered by the ensemble in 2009. The idea for the opera began to take form in an interdisciplinary conference where Parra encountered the physicist Lisa Randall. Known for her work in theoretical particle physics, Randall has focused much of her research on the development of models involving extra dimensions of space. One of her most renowned books, *Warped Passages*, explains this subject for laymen. Having read the book , Parra found himself so inspired by the ideas presented, that asked Randall to collaborate with him in the creation of his new opera.

Randall accepted the task of writing the opera's libretto, even though she had no previous experience in this field. The libretto presents a amorous couple, the Soprano and the Baritone, both scientists. As the tensions of their troublesome relationship unfold, the Soprano begins to take note of additional dimensions in her world to which her partner has no access. As she projects herself to other dimensions, the Baritone begins to believe his companion and follows her into the fifth dimension.

The opera is composed for the two aforementioned singers, eight players and live electronics. It comprises seven acts, referred to as "Planes". Parra conceived both the instrumental/vocal writing and the electronics in a manner intended to reflect the physical properties of the various dimensions visited throughout the work. The electronics in particular are used to represent the foreign dimensions and therefore first appear in the fourth act (Plane IV), when the Soprano begins her journey into the fifth dimension. Likewise, the changes in instrumental dynamics grow much more intense in the fifth dimension, creating a mass of rapid eruptions and disappearances (Ex. 20); sections of the opera taking place in the normal physical world feature a slower and less extreme dynamic evolution.

Thus, Parra attempted to compose a work in which the electronics not only create a new and contrasting sound world but also delineate dramatic aspects of the text.

Ex. 10 : Rapidly varying dynamics and gestural density in Plane IV

II.3.2. Electronics

The electronics in *Hypermusic Prologue* are played over a set of six loudspeakers arranged in a circle around the audience. At least one microphone is required for each musician and if possible, two for the wind players and anywhere between two and eight for the percussion, depending on the hall. The two vocalists must use wireless microphones throughout the performance.

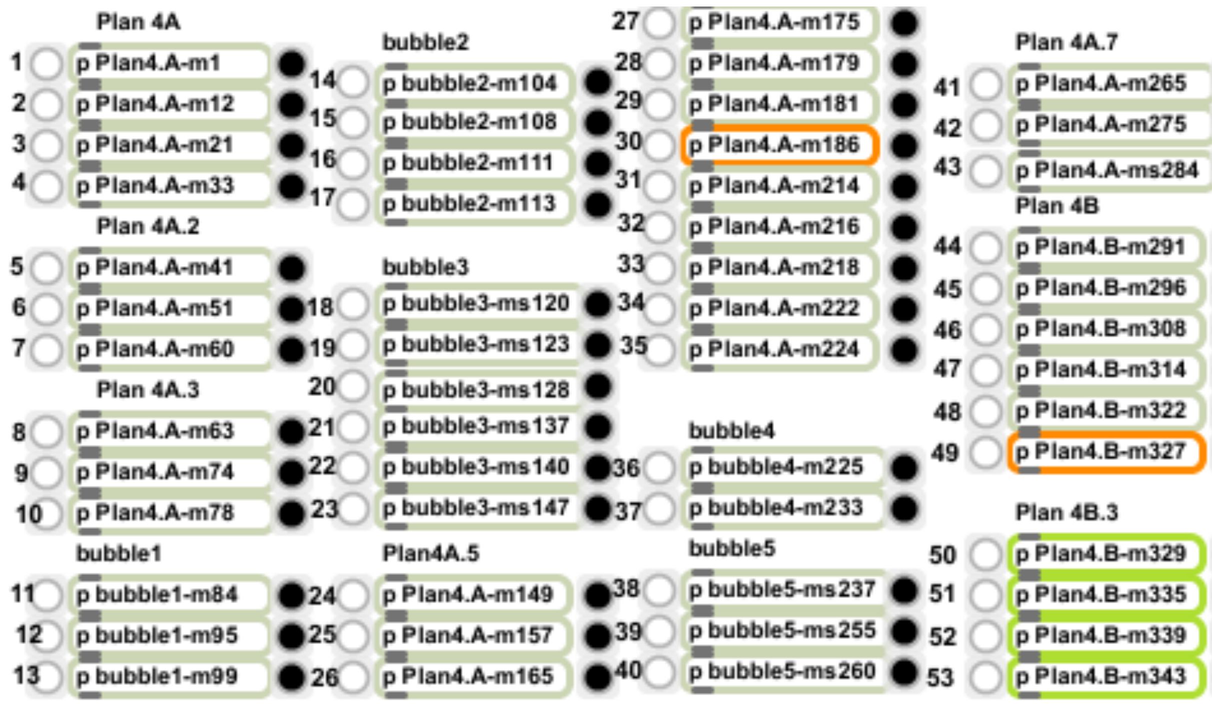
The opera relies upon an intricate patch to control almost all properties of the electronics. Treatments and sound files are triggered by the flautist who is equipped with a MIDI pedal, though this task is executed by the sound engineer in some performances. Of the eight players, only the strings – violin, viola, cello and contrabass – are transformed in real time, as well as the two vocalists. Nevertheless, all instruments and vocalists are amplified even when no electronics are applied. In order to avoid an abrupt change in volume and space upon in the beginning of Plane IV.

Four principal forms of electronics are managed by the patch:

- Independent real-time treatments – the input signal from each of the strings and voices is treated directly, independently of the other instruments, according to predefined parameters. These effects include: delay, harmonisation, transposition, filtering and granulation.
- Interdependent real-time treatments – the input signals from both the treated instrument/voice and an additional instrument/voice are required in order for the electronics to function. One of the signals is transformed while the other varies the parameters of the effect. This is mainly applied to the vocal roles, especially the soprano. The effects include: cross synthesis, granulation and resonators.
- Sound files – a hexaphonic sound file serving as a solo *Electronic Interlude* is played at an important structural point of the work. Though it first emerges from within a string texture, the file is soon left to play alone. Additional, shorter sound files are triggered towards the end of the piece atop an intricate instrumental texture, thus blending with the live-electronic treatments.
- Spatialisation – the live-electronic treatments and sound files are output on six channels. The spatialisation is programmed into the patch in such a manner that it is difficult to access and modify.

Each cue in the piece is a self-contained agglomeration of transformation processes (and possible sound files) contained in sub-patches (Ex. 21). The triggering of each cue sets off these processes, which are either automatically shut off upon completion or at the onset of the following cue, or must be manually shut off by the sound engineer. As with *Voi(Rex)*, the patch was designed at IRCAM and follows the institution's aesthetic tendencies. Therefore, almost all live electronic processes are carefully timed to the millisecond and synchronised with musical elements of the score .

The real-time treatments are highly dependent upon both the amplitude of the input signal but also the variation in amplitude. Several effects only begin to sound when a certain amplitude threshold is surpassed; others will only sound when a sufficiently large increase in amplitude occurs, as when a player passes from ***pp*** to ***ff***. Thus the entire functionality of the electronics is precarious and quite vulnerable to changes in acoustics, the players or their disposition. Consequently, the sound engineer must dose the volume of each effect in order to avoid dynamic peaks and feedback, and in order to assure that all the effects may be heard. In performance, it is advised to carry out this task using a MIDI faderboard in which each fader or knob is assigned to each of the eleven controllable effects (several effects are not output directly from the patch and cannot be mastered in this way). The sound engineer therefore plays a vital role in the realisation of *Hypermusic Prologue* and must be able to both anticipate and quickly react to the musicians' actions.



Ex. 11 : Subpatches containing the many treatments for each cue

While one sound engineer coordinates the balance of the different effects, a second sound engineer must balance the electronics with the amplified instrumental sound. This engineer can furthermore create an additional layer of spatialisation, though this is not asked for by the composer. As the spatialisation is dictated by the patch and cannot be managed using a MIDI controller, the only manner of regulating any spatial inadequacies engendered by changes in hall acoustics is by individually modifying the output volume of an entire channel. Since the predefined spatialisation managed by the patch does not include clearly identifiable trajectories or a precise use of speaker location, but rather creates an all-embracing sound that varies in presence and density, this additional control of the space need rarely be used. The desired effects of changes in presence and density can be created by properly regulating the hall volume and effect volume. Nevertheless, during the *Electronic Interlude* in which the differences in spatialisation are largely imperceptible, the possibility of manipulating the spatialisation can add a great degree of interest to an otherwise static passage.

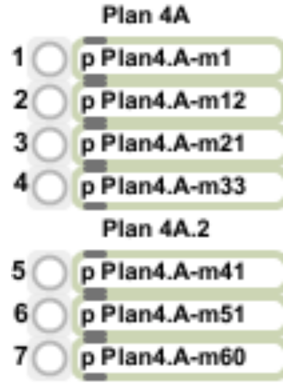
II.3.3. Notation

Hypermusic Prologue is a representative example of a work comprising complex electronics of a very significant scope, yet whose score contains no indication whatsoever as to the existence of the said electronics. Though electronics played an important role form the very conception of the piece, Parra first completed the instrumental score in order to satisfy the requirements of the commissioning bodies, ensemble and editors. Only thereafter was the patch programmed and then finalised during rehearsals. As a result, the patch and the documentation provided with it serve as an electronic score instead of the printed orchestral score.

As with *Mixtur*, a detailed description of the technical set-up used in the first performance is provided in the documentation. Unlike Stockhausen however, Parra includes the exact numbers and models of microphones and speakers as well as an output patch for the mixing console. Furthermore, the patch initiation procedures are explained, as well as the necessity of a MIDI faderboard.

The remaining information required for successful operation of the electronics during the performance can also be found in the documentation and patch. Armed with sufficient patience, the sound engineer can extrapolate the following details:

- Cues – there is no indication of these in the performance score. However, the numbers of the measures on whose downbeats the cues are to be triggered are noted in the patch. In the main screen of the patch, one can find a list of subpatches whose names include their measure numbers. These numbers correspond to measures in the score, beginning in Plane IV; however, they are offset by 218 measures (Ex. 22).



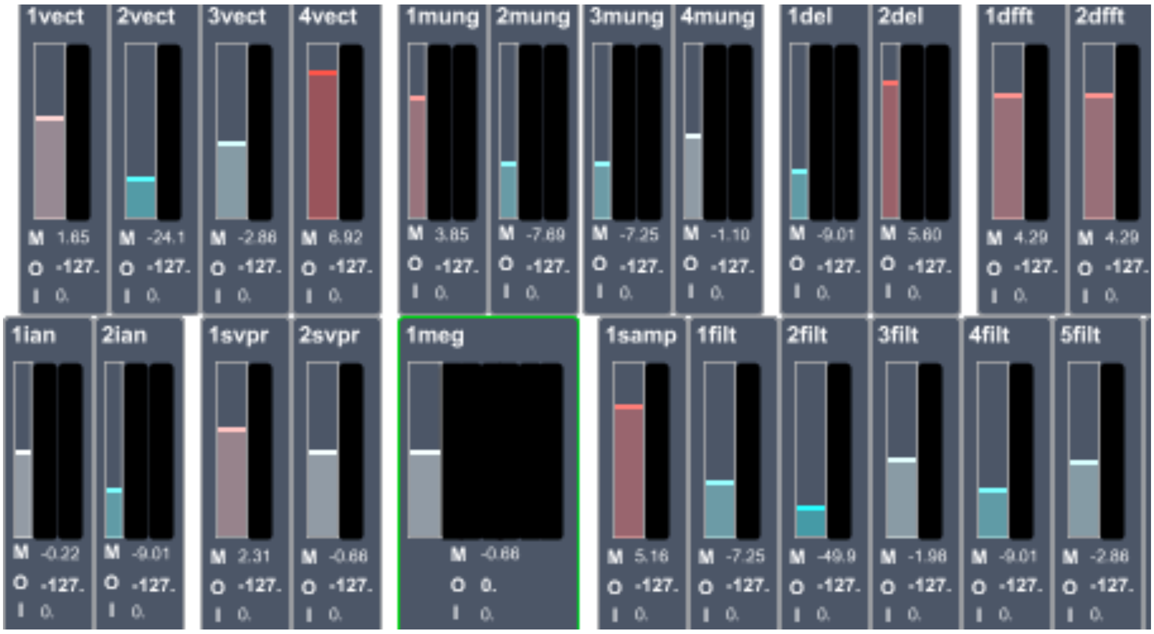
Ex. 12 : the occurrences of the cues in the score can be determined by the Plane numbers and measure numbers in the names of hte subpatches

- Treatments – a spreadsheet indicating the different types of treatments that occur at each of the 109 cues (still offset by 218) is included. The spreadsheet states the name of the treatment and the instruments affected by it (Ex. 23).

mesure	giz	vect	mung(>fsh>comb)	del/filt	dfft	sfil
74	Vc	Q			BAR	
	1 2	1 2 5 6			rev 1	
78	Vln VlA				BAR	
					rev 1	
84	Q		SPR		BAR	Q / (SPR + 1samp)
	rev		rev 1 2		rev 1	rev 1 2 3 4

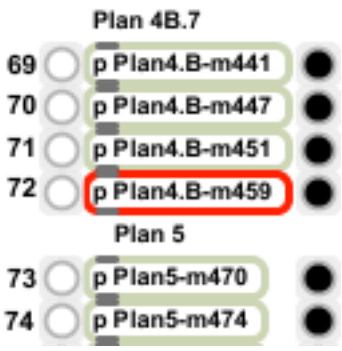
Ex. 13 : offset measure numbers (y-axis), treatments (x-axis) and the instruments/vocalists affected

- Treatment volume – the mixing window of the Max/MSP patch shows the real-time output levels of each of the effects. This provides the sound engineer with a visual indication useful for balancing the effects with the faderboard (Ex. 24).



Ex. 14 : Mixing window of the patch showing the levels of each effect.

- Resets – at certain moments in the work, the patch must be reset. This is indicated in the main screen of the patch by the colour of the subpatch. Subpatches marked in red require a manual reset (Ex. 25).



Ex. 15 : Red border indicates that the patch must be reset manually at the end of the event

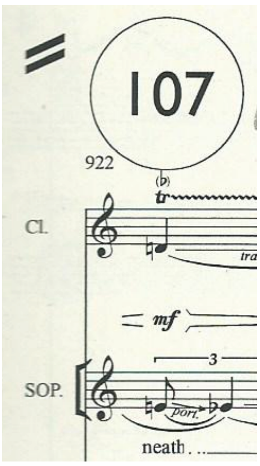
- Spatialisation – the spreadsheet indicating the different types of treatments also states the number of the loudspeaker on which it will be played (Ex. 26).

vect
Q
1 2 5 6
Q
1 2 5 6

Ex. 16 : the numbers indicate the output channels on which the treatment will be defused

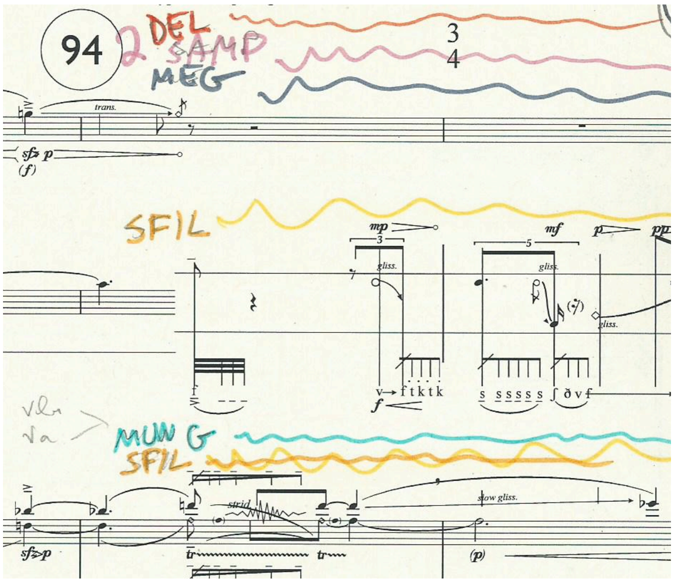
Needless to say, it is quite difficult – indeed almost impossible – to make use of this information in its current format. The above details must be reflected in the score in order that the sound engineers may fulfil their roles reliably and in coordination with the ensemble/vocalists. Therefore, in the single set of performances of *Hypermusic Prologue* that were not executed by IRCAM, an "electronic score" was generated to facilitate the work of the sound engineers. This electronic score represented the relevant information as follows:

- Cues – after the 218-measure offset was accounted for, the number of each cue was written into the score at the appropriate position (Ex.27).



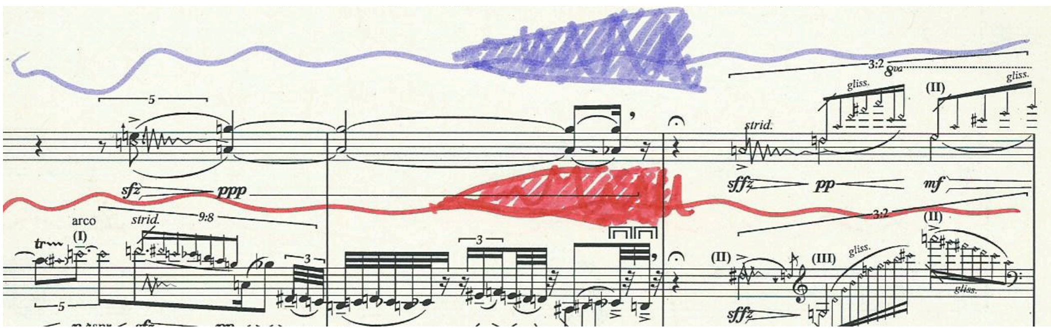
Ex. 17 : Clearly marked cue number in electronic score

- Treatments – each treatment was assigned a colour. When a treatment is implemented, lines of the colour corresponding to the treatment appear in the score above the staves of the instruments to which the treatment is applied (Ex. 28).



Ex. 18 : Different types of treatments indicated in different colors above the instruments to which they are appllied

- Treatment volume – the patch showing the real-time levels of the remains in the foreground of the screen throughout the performance so that it may serve as a visual monitor. The sound engineer uses this monitor as well as his hearing to create an appropriate balance with the faderboard. When a particularly important volume modification is required and can be anticipated, this is marked in the score with an expanding or contracting wedges in the appropriate colour (Ex. 29).



Ex. 19 : Coloured wedges indicate important dynamic changes that the sound engineer is to carry out

- R

esets – these are clearly marked in the electronic score at the earliest moment in which it is possible to reset the patch without disturbing the continuity of the performance.

- Spatialisation – the electronic score does not include information concerning the spatialisation as there is no possibility of controlling it directly through the patch. Additionally, the original spatialisation is relatively balanced throughout the hall; consequently, the auditor does not hear clear spatial trajectories but rather changes in the density of the electronics, which can be reinforced with the proper management of the treatment volume. Nevertheless, the sound engineer managing the balance in the hall may adjust the spatialisation by ear if necessary.

The use of an electronic score is a basic necessity for the performance of *Hypermusic Prologue*, as the opera demands that many intricate and volatile processes be followed and controlled simultaneously. The information supplied by the patch cannot be integrated and carried out in real-time, and an interactive relationship between musicians/vocalists and electronics cannot be realised. However, an electronic score prepared by the composer and technical assistant themselves would better convey the piece's intention.

II.3.4. Benefits and shortcomings

The shortcomings of a score devoid of electronic indications are obvious. The disadvantages of providing all the relevant information in separate files and within the patch also need not be expounded. It is obvious that future performances *Hypermusic Prologue* necessitate the fabrication of a proper electronic score. For lack of any other score, the electronic score generated by the sound engineers for recent performances of *Hypermusic Prologue* will serve as a model for analysis for the purposes of this research.

Cues and resets – the indication of cues in any score requiring triggering is indispensible. The cue numbers must simply be marked in a sufficiently eye-catching manner above or below the staff of the player performing the triggering. Likewise, manual patch resets must be marked for the sound engineers in a obvious manner (such as boxed text or large font size). This is a basic yet extremely important detail clearly marked in the electronic score.

Treatments – the use of colours to indicate the different types of treatment in the electronic score bears the advantage of allowing the sound engineer to quickly identify the treatments applied at any given moment. Additionally, the faderboard may be marked using the same colours as the score so that the faders may quickly be associate with their respective treatments. In a highly detailed and fast moving score such as that of *Hypermusic Prologue*, textual information is concerning the electronics is difficult to discern and process rapidly; the use of colours provides another notational dimension that can be easily differentiated from the many additional details present in the score.

Despite the effectiveness of this notational method, it is not a sustainable solution for electronic notation as no editor will undertake the high costs associated with printing scores in colour; consequently, another solution must be found. As a conceivable alternative for colours, for example, one may employ patterned textures (such as dotted lines, striped or dotted fillings, etc.). It is clear that when eleven different treatments are used in frequent alternation in a score that is saturated with notes, graphics and texts, a visually instinctive method must be used so that the sound engineer may regulate them quickly and reliably.

Treatment volume – as with the use of colours to indicate treatments, the use of coloured wedges to indicate important crescendi or diminuendi has the advantage of being visually distinct from the rest of the score and therefore easy to respond to rapidly. Of course this provides only a partial indication of volume, as it does not demonstrate how volume should be regulated with respect to other instruments, nor the complex interaction scheme that directly affects the treatment volume.

Spatialisation – the lack of spatialisation in the electronic score is clearly disadvantageous; however, as previously mentioned, the principal sensation of space is easily controlled by the volume of the effects. Nevertheless, the indication of the desired spatialisation and the loudspeakers form which the electronics are to be diffused would serve a useful descriptive purpose, to aid the sound engineers in following the progression of the electronics throughout the score. Likewise, the spatialisation of the *Electronic Interlude* could benefit from some indications. In recent performances, the use of space in this part was improvised by the sound engineers; if this (or a different approach) is desired in future performances, it should be indicated in the score.

III. CONCLUSIONS

The three compositions discussed demonstrate the many complexities that render notation of live electronics so challenging. It is clear from the wide variety of compositional approaches and technical means employed that a single notational system cannot possible reflect the breadth of this genre. Nevertheless, certain guidelines can be extrapolated from the issues encountered in these works. These guidelines can be arranged in categories that are sufficiently broad that they may be common to a large number of pieces using electronics.

Technical set-up – in order to reproduce a technical set-up in different halls with different materials, the indication must be sufficiently general and include some explanation of how the piece may be performed with less equipment than originally expected, as in the scores of Leroux and Stockhausen. A detailed description of all the material used, the exact patching scheme and setting of each microphone or loudspeaker, as in the documentation of *Hypermusic Prologue*, are of little use when performing in a different location. This section of the score should also clarify the composer's sound world as much as possible, in non-technical terms. If the general conception of space, sound and atmosphere are understood, they can be recreated by an engineer using whichever means are at his disposal.

Pitch/frequency-based indications – when the electronic treatments or sound files are significant, clearly discernable pitch material, whose temporal parameters are stable, it is reasonable and logical to use the standard five-line staff. This notation is universally understood and benefits from being both prescriptive and descriptive to some extent.

Dynamic indications – dynamics and volume control are perhaps one of the greatest notational difficulties. Dynamics can vary wildly as a function of hall, material, the performer, even the performer's disposition at the time of the performance. Furthermore, traditional notation does not have sufficient means of expressing this parameter. Therefore, a system for the notation of dynamics must be devised that is both visually simple to read and does not rely upon absolute units. An ideal system would indicate the level of electronics in relationship to the performers and their direct or amplified sound. It would be both descriptive and prescriptive in the sense that it explains what is to be heard, and that the gesture necessary to achieve this result can be deduced from the notation. None of the works analysed in this research provide helpful instructions concerning dynamics, even though it is one of the most vital characteristics of the music.

Spatialisation – notation of this element largely depends on the nature of the spatialisation: whether it contains precise trajectories or states, creates a general atmosphere, is predetermined or aleatory. If the spatialisation is very precise or predetermined as in *Voi(Rex)*, then Leroux's notation is adequate. It describes from where the sound should emerge and – should the engineer be required to spatialise the sound manually – how to do so. In pieces such as *Hypermusic Prologue*, in which the spatialisation creates a more general feeling, such as that of an internal or external space, of a dense or rarefied sound world, of being surrounded or isolated, then more descriptions are required. These are best expressed in words explaining the composer's desire, as the exact technical gestures required to achieve this will change from hall to hall. Concerning more aleatory performances, especially using controlled aleatoric methods, a system integrating Leroux's circled-digit notation can be integrated in order to provide the engineer with clear possibilities upon which he can improvise.

Aleatory electronics – when the engineer is free to improvise or perform along with the rest of the players, it is useless to provide accurate descriptive notations as it is impossible to foresee the sound result. Instead, prescriptive indications as to the gestures of the engineer should be provided, alongside general explanations of the nature of the interaction.

Highly automatised electronics – the main conclusion one can draw form the three works discussed, all of which require adjustments in performance that are not indicated in the score, is that even works with highly automatised electronics must provide a means of making corrections in real time. In both Leroux's and Parra's compositions, aspects of the electronics that should be entirely controlled by the patch are often modified in performance by the engineers using an external MIDI device or the mixing console for the entire work. The parameters that the engineer may need to control in performance should be indicated in the score, with some explanation of the desired result. Descriptive notation is appropriate to this end, as the composer has clearly predetermined the sound result, and as prescriptive instructions are likely to be too precise to be useful.

Complex and very detailed scores – in works such as *Hypermusic Prologue*, it is best to avoid saturating the score with further textual instructions or copious symbols. A visually obvious system must be devised that allows the electronics to be easily read and distinguished from the remaining instrumental/vocal parts. Use of colour, different line thicknesses or textures may be useful in such a case, should the means of producing and printing such a score in many copies be available.

As mentioned in the introduction, this research does not claim to provide a solution to the notational woes of live electronic, nor to propose a one-size-fits-all system. However, the conclusions drawn from the analyses of the three works as well as the guidelines expounded above may serve as a fruitful basis for the development of future notational systems. Should composers approaching a new composition consider their use of live electronics along these guidelines and craft their notational method in accordance, it is more likely that the notation will better serve the piece. Should this approach be adopted by many composers, it is possible that uniformities will begin to emerge, – just as they did with notation of extended techniques – which will render the task of writing and performing live electronic music much simpler and more efficient than it is today.

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