# Interpretation and Space

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## Introduction

### Sound, time and space

In a natural state, any generated sound cannot exist outside its context. Regardless of where it comes from, it will always be associated to more or less complex acoustic waves generated by phenomena such as reflection, absorption, diffraction, filtering, the Doppler effect and so on... The absence of effect, obtained in an anechoic chamber, is in fact only one particular case of environmental effects.

Regarding the definition of sound, one admits that frequency is one aspect of time. One can not define frequency, period or wave length without making reference to time. Similarly, we can consider that space is also an aspect of sound/time and that the composer is confronted by a space-time problem. Space-time is none other than the fourth dimension in which man exists. Sound has the same destiny : it is born, lives and dies, leaving an impression of its existence on the environment (rebounding, etc...). We conclude that like people, sound needs air (an elastic medium) to exist and in a vacuum, we meet neither people nor sound.

Space, as a real parameter in writing music like pitch or timbre , is a central issue in contemporary music composition. "Be it electroacoustic or computer generated, music of today is spatial music... the notion of musical space has characterized the style of our epoch. / *Qu'il s'agisse de la musique électroacoustique ou de l'art issu de l'ordinateur, la musique de notre temps est une musique de l'espace...la notion d'espace musical a caractérisé le style de notre époque."* (Hugues Dufourt, 1991).

The title of a piece like *Timbres, Espaces, Mouvements* by Henry Dutilleux indicates how the spatial parameter can merge with sound.[1]

Just like it is not imaginable to write an instrumental piece without thinking about pitch and timbre, it is no longer conceivable to ignore the spatial consequence of a musical work. Consequently, it would be idealistic to think that music exists only through its score. It would be very limiting to leave acoustic consequences contingent on interpretation to chance, because there would surely be consequences.

The composer who is concerned about understanding the construction of his music has to consider his piece in the following sequence : "composer-performer / diffusion-acoustic effects / the listener-understanding".

### Modifying the sound space through the score

The advantage of spatialization, or putting sound in space, is to compose using a new attractive parameter which allows to better fill the space-time relationship.

When sound has an organized spatial life, it can take over the listener in his own physical space and thus break down the two-dimensional barrier between the performer and the audience, a barrier that distracted listeners often fall prey to.

1. In this piece, Henri Dutilleux uses an unusual instrumental ensemble in which violin and viola are excluded. The cello and bass alone are confronted by the wind family (bright and luminous). The composer's goal is to create the feeling of immense space, suggested by the painting "A starry night" by Van Gogh. Spatialization is suggested by combining three parameters : the orchestra size points out a spectral desire for creating sound material ; the particular arrangement of the musicians (cello in the center, bass right and percussion left) ; the musical writing allows the movement of music in space.

Reprint from : *Trends in Gestural Control of Music*, M.M. Wanderley and M. Battier, eds.

In fact, even if this parameter was rarely used in an explicit way in the past, it is obvious that we can detect some "spatialized sound material" in many symphonic pieces due to the orchestration itself and consequently coming from the will of the composer.

Every instrument, from the flute to the bass, has a more or less strong natural ability to spatialize sound according to its register, timbre and directivity.

The orchestra is of course a wonderful "machine" for transmitting sound, a kind of spatializer. In Beethoven's music we often feel energy coming from the back of the stage from the percussion instruments, moving forward with the brass and extending toward the sides with the strings. Maurice Ravel's Bolero is one long continuous crescendo from beginning to end coming from the furthest point back in the orchestra and finishing at foremost in complete presence. A fast orchestral phrase played by the strings, from the lowest to the highest octaves will always create a panoramic sweeping from right to left.

The spatial parameter is very interesting to explore provided that one accepts the acoustical constraints of concert halls. The composer's domain of research will be enlarged, enabling new ways of exploring the space-time relationship.

## Modifying the sound space through positioning

The composer of acoustic instrumental music can find creative and clever solutions by using "natural" systems of spatialization. The position of the performers can be studied. For example, one can use a spectral layout. Performers could be placed around or among the audience. Though unusual, it is one way to play with the space, performers could also physically move while playing.

The choice of specific places, with special acoustic characteristics or the use of natural resonators could also be interesting solutions.

Research in this field has been prolific and many solutions from specific composers have become references, such as :

- *Central park in the Dark*, by Charles Ives (1906)[2], *Gruppen* by Karlheinz Stockhausen (1958)[3] or Pierre Boulez's *Répons* (1981)[4].
- Current electronic techniques have provided a good deal of control and are dependable enough to be utilized in electroacoustic and live electronic concerts.
- The Homo-parleur by Georges Boeuf and Michel Redolfi (1976)[5] was a lively response to the spatialization problem.
- The Acousmonium[6] created by the GRM is a real spatialization tool that permits almost complete space-time immersion even if it is a bit difficult to use in practice.

2. In this piece, the strings suggest a nightly continuous noise on which are added various musical objects, creating a lively wild environment. One can hear successively a singer, subway sounds, firemen, horses, brass bands. Sound spatialization is created by the movement of the musicians and by the nature of some surprising sounds.
3. A piece created for three orchestras, each of them directed by a different conductor. Stockhausen has often given interesting answers to the spatialization problem (*Carré* for four orchestras and choirs; "acoustic sphere" created at the universal exhibition in Osaka; performers playing in an helicopter...).
4. A piece combining acoustic and electronic sources written for three sound elements. At the center is the orchestra (24 performers), 6 solists are around the audience, the computer (4X) receives the sound played by the soloists, transforms the sound and transmits it to the speakers to give the electronic response to the instrumentalists' proposal.
5. These composers gave a lively answer to the spatialization problem. A speaker was placed on each performer-actor. Each "homo-parleur" is responsible for their space according to their movement.
6. The Acousmonium of the GRM, created in the 70s by François Bayle (see Bayle – 1993), is an orchestra made with sound transmitters used for interpreting live acousmatic music. It is composed of 60 speakers, organized in particular regions in the space, corresponding to different planes. When played live, the Acousmonium has proved that it was a wonderful diffusion tool allowing the investigation of the whole space-time.

Even though all these new techniques are linked to the use of the speaker they have considerably spurred creativity.

### The spatialization layout

Contemporary music is moving towards live electronic music. The instrumentalist, with the help of new techniques can enlarge the natural limits of the instrument. The spatialization of such an arrangement could be carried out by simply using stereo, but by using a number of speakers depth and breadth are taken on. Even three-dimensional spatialization is realizable depending on the placement of the speakers. A computer checking system called a "spatializer" is indispensable in managing the layout. The ideal spatializer would be capable of managing various parameters such as : reverberation – to simulate distance ; filtering, dephasing for subjective sound placement as well as psycho-acoustic and physical parameters (like the doppler effect).

Such a layout allows sound to have its own life in space, becoming a "sonorous entity" that transmits the sensation of a living presence to the audience.

A number of spatialization layouts are given in the following sections.

### Layout control

Apart from the spatialization system, the composer has specific types of control systems available. Systems that allow the instrumentalist to control specific events while respecting interpretation, thus time, are preferable. A sound tape simply superimposed on an instrumental performance is rarely satisfying musically, although the result is sometimes surprising like in *Kontakte* by Stockhausen (1960)[7].

A performer whose only role is to set off a series of events is less and less satisfying and the composer himself at the mixing board triggering the events rarely gives the impression of music being born before our eyes (or ears).

The composer could very simply integrate a system of pedals that the solist could trigger as desired in accordance with musical time. The MAX program[8] combined with the MSP software[9] allows for in depth use in this area. The instrumentalist is capable of controlling all sorts of possibilities like linking score follower to instrumental play, pitch tracking, sound envelopes as well as other parameters. We can thus imagine a system capable of the evolution of the diffusion of sound in space (from front to back or top to bottom) or the application of sound treatments to the sound regarding its pitch, intensity or spectral content. The composer, at this point will feel as though he has really integrated the space-time parameter in his/her writing as well as timbre or pitch. Moreover, the instrumentalist is capable of controlling all the music transmitted toward the audience.

## Spatialization techniques through amplified sound

We have seen that when using an acoustic orchestra, sound spatialization can be considered by the composer in writing the score. Listening to the music or sounds is dependent on a continuum of sound sources position, including direct sound, determined by the sound source position and indirect sound characterized by the environment. When electronic or digital sounds are diffused, it is important to reconstruct a balanced and coherent sound space. We are now able to create virtual sound spaces. Current sound diffusion techniques allow one to surpass traditional orchestral possibilities. All sorts of positions or locations of virtual sound sources can be proposed to the listener. Nevertheless, all problems have not yet been solved and composers don't always have well-defined ideas about the host of possibilities available to them.

7. This piece for tape, piano and percussion requires absolute time precision. It is necessary to be very familiar with the tape to play this piece.
8. Opcode system : www.opcode.com/products/max - Ircam : www.ircam.fr.
9. Cycling74 : www.cycling74.com/.

## Transmission of recorded music

The first spatialization trials of broadcasting instrumental recorded music were in stereophony, which appeared in 1958. The easiest method consisted of making a sound recording that would best recreate the sensation of space.

Recording with two microphones reproduces the sound image perceived by a listener seated in an optimal position in a concert hall. The goal is to reproduce, as naturally as possible, the atmosphere of the room where the recording has been done. A lot of techniques provide a more or less well placed sound source, depending on the choice of microphones, their position and direction. What is interesting about this method is that it is based on a physical principle and not on the use of complex systems.

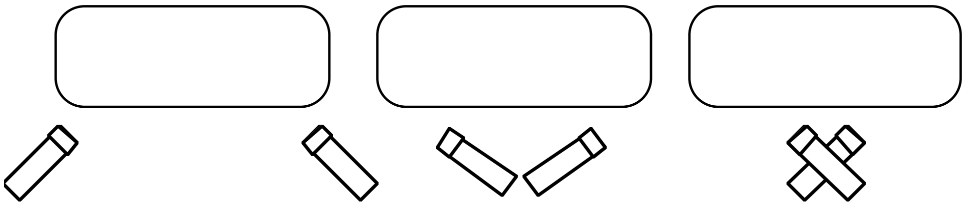


Fig. 1. Examples of microphone positioning for stereophonic recording (see Caplain – 1980).

## Space and multi-track recording

With the development of multi-track recording, sound recordings of each instrument can be accomplished independent of each other with more precise and close range positioning. Sound spatialization, the reconstruction of stereophony is thus artificially created, through the use of a mixing board.

The first spatialization control is the panning fader which is used for moving the virtual sound source between two speakers, by changing the level of each of them.

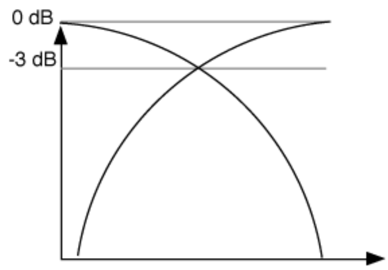



Fig. 2. Variation of the sound levels of a sound from two speakers with the panning fader.

The sound engineer can use different tools which help him to artificially balance the sound. This balance must be obtained in many areas : the spectral balance (filters, delays, harmonizers, flangers…), the balance (compressors), the depth and the different sound planes (reverberation) and the panoramic balance inside the stereophonic space (see Hugonnet, Walder - 1998).

## Space and electro-acoustic music

In conventional stereophony or in quadriphonic transmission, it is possible to preserve the sensation of distance and direction of the sound sources, creating the illusion of a position in a virtual acoustic space. In traditional acoustic music, things are relatively clear because of accumulated experience of many decades. For synthetic sounds, things are more complex because the situation is new.

For stereophonic transmission of artificial sounds, the techniques and tools adopted for mixing natural multi-track recorded sounds can be used, but it is interesting to explore a larger space than simple stereophony, in particular by multiplying the points of diffusion.

## Chowning spatializer

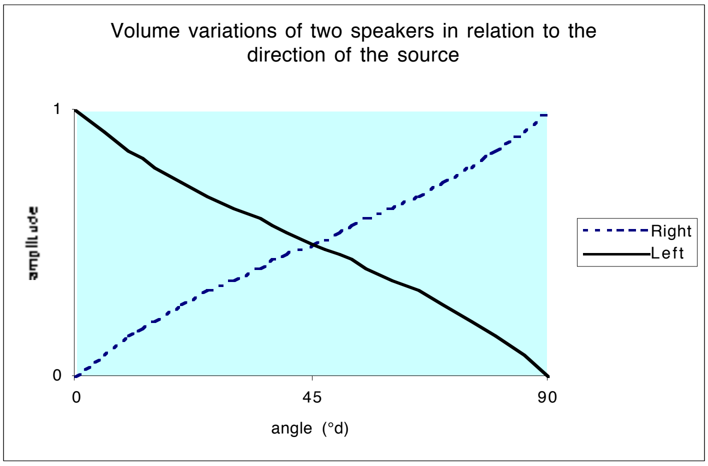
John Chowning is one of the first researchers to have described a three-dimensional sound spatialization system in depth (see Chowning - 1971).

He shows that the listener requires two kinds of information : that which defines the direction of the source relative to the listener and that which defines the distance of the source to the listener.

Regarding direction, this information is both the arrival time difference of the signal between the two ears and the pressure-level difference of high-frequency energy in the two ears, resulting from the shadow effect of the head when the source is not centered.

According to distance, this information is both the ratio of direct energy to indirect or reverberant energy and the loss of low-frequency sound components as the distance from the listener increases.

With these different cues, Chowning proposes a quadriphonic sound spatialization system. To control the sound level according to the direction of the source, he uses a tangential function as shown in the next picture.



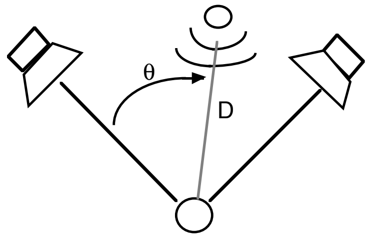




Fig 3. Variation of the sound pressure levels of a sound in two speakers in relation to the direction of the source.

To simulate distance, it is necessary to synthesize and control the reverberant signal as well as the direct signal such that the intensity of the direct signal decreases more with distance than does the reverberant signal. The amplitude of the direct signal must be proportional to $1/D$, where D is the distance from the listener to the virtual sound source. The variations of the amplitude of the reverberant signal in relation to the distance fom the source depends on the size of the room. In his experiments, Chowning made the amplitude of the reverberant signal proportional to $1/\sqrt{D}$.

In the case of a moving sound source, velocity information is given by direction and distance variations and by a frequency shift due to the Doppler effect. The Doppler effect can be simulated by sound transposition corresponding to a frequency variation proportional to $dD/dt$ (radial velocity).

Reverberation is bound to the physical characteristics of the room we want to simulate. In particular, it depends on the size, the shape and material used in construction. To simulate a sound source in an enclosed space, it is desirable that the artificial reverberation surrounds the listener and be spatially diffuse.

A simple method consists in transmitting the reverberation from all speakers at the same intensity (following the $1/\sqrt{D}$ function). When the source is far from the listener, the reverberation tends to mask the direct signal and eliminate the cue for angular location. In order to eliminate this deficiency, the reverberant energy can be proportional to $1/D$ and a local reverberation, proportional to $1-(1/D)$ can be transmitted from the same speaker as the direct signal.

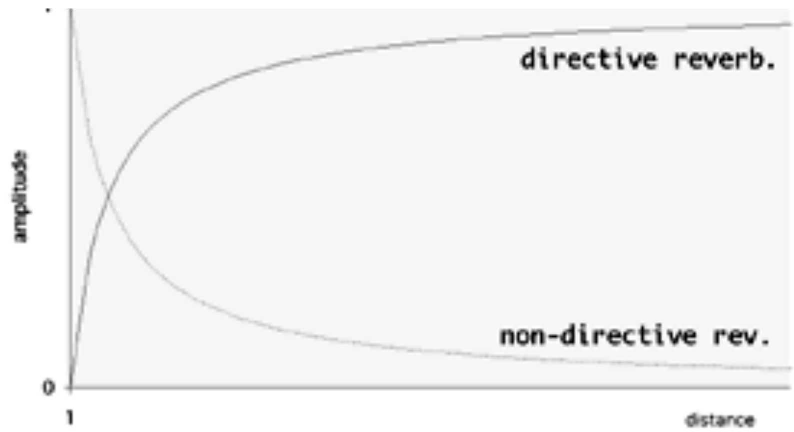



Fig. 4. Variations of non-directive and directive reverberation signals in relation to the distance from the sound source.

This technique is a good approximation of a real acoustic situation, for as the distance from the sound source increases, the distance from a reflecting surface decreases, thereby giving the reverberation some directional emphasis.[10]

However, this technique doesn't consider the atmospheric attenuation of sound according to its spectrum.

## The Ircam Spat

The Chowning proposals have been ameliorated by different research centers or industrialists. Some new sophisticated spatializers have been constructed. Among them, the Spat by Jean-Marc Jot at Ircam is the most elaborate.

The first versions of the Spat were developed with the Station d'informatique musicale (SIM) built by IRCAM. Spat now exists on Macintosh computers in MAX/MSP environment[11]. All of Spat control parameters can be changed in real time. This can be done with MIDI and sensors, with Ethernet, serial/ USB transmission or inside the machine using sequencers or by programming directly with MAX.

Spat offers many control parameters according to perceptive criteria. These criteria concern the description of simulated acoustic space (room presence, reverberance, envelope, heaviness, liveness), the parameters of the diffusion system (position, radiation, orientation) and the localisation of the source (distance, azimuth, elevation).

10. Example : John Chowning. *Turenas* (1972), Mainz, Germany: Wergo (WER 2012-50), 1988.

11. As of this writing, it also exists on IRIX SGI and Linux PC running jMax (note of the editors).

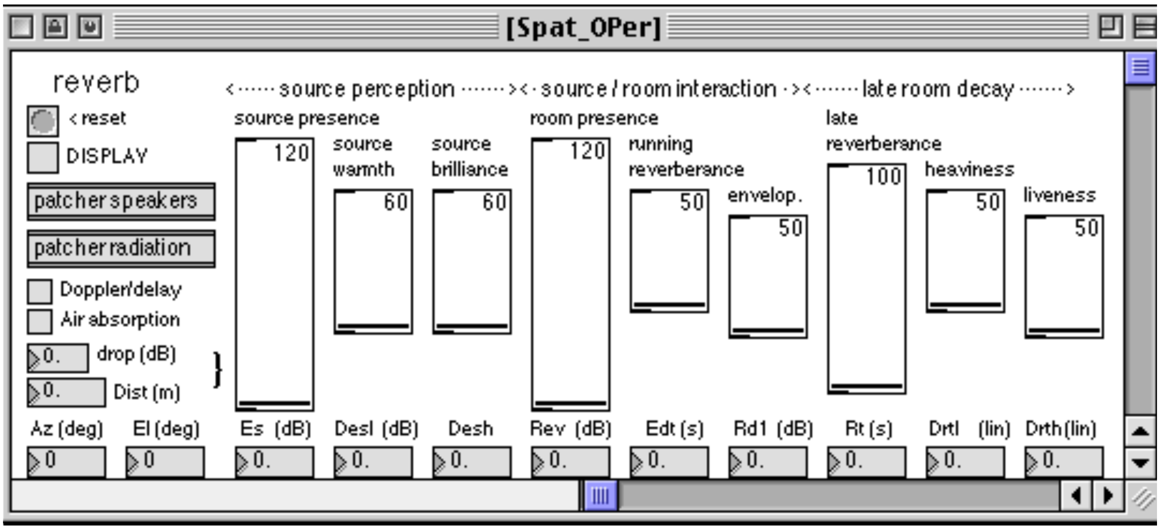



Fig. 5. Main control window of the Spat.

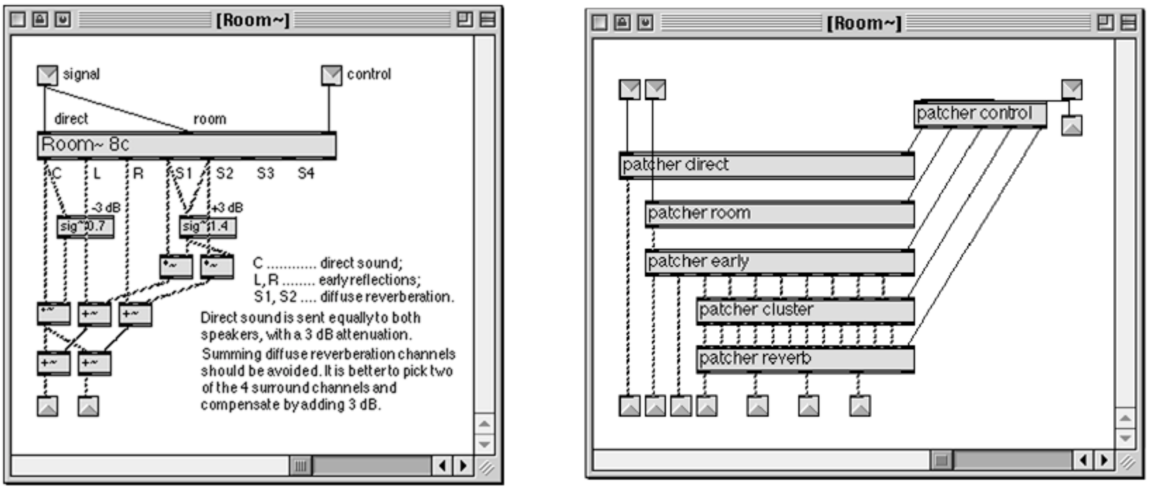



Fig. 6. Main DSP objects connected in Spat.

Spat can be used in different listening situations (binaural, stereophony, quadriphony, Dolby 3/2...).

Spat'slimitslie in the processing power required for use. On the SIM station, the spatialization of one sound track over four speakers required almost one full processor. On a 300 MHz G3 Macintosh computer, this operation requires all the processor's activity. It is not possible to use this tool in real time (live) for the spatialization of more than one sound source at a time with this system.

Systems like this cannot simulate sound if the sound source is not placed in the same room as the listener. In this case, it is necessary to apply complex absorption coefficients to modify the sound. This would be particularly useful for theater, opera or radio.

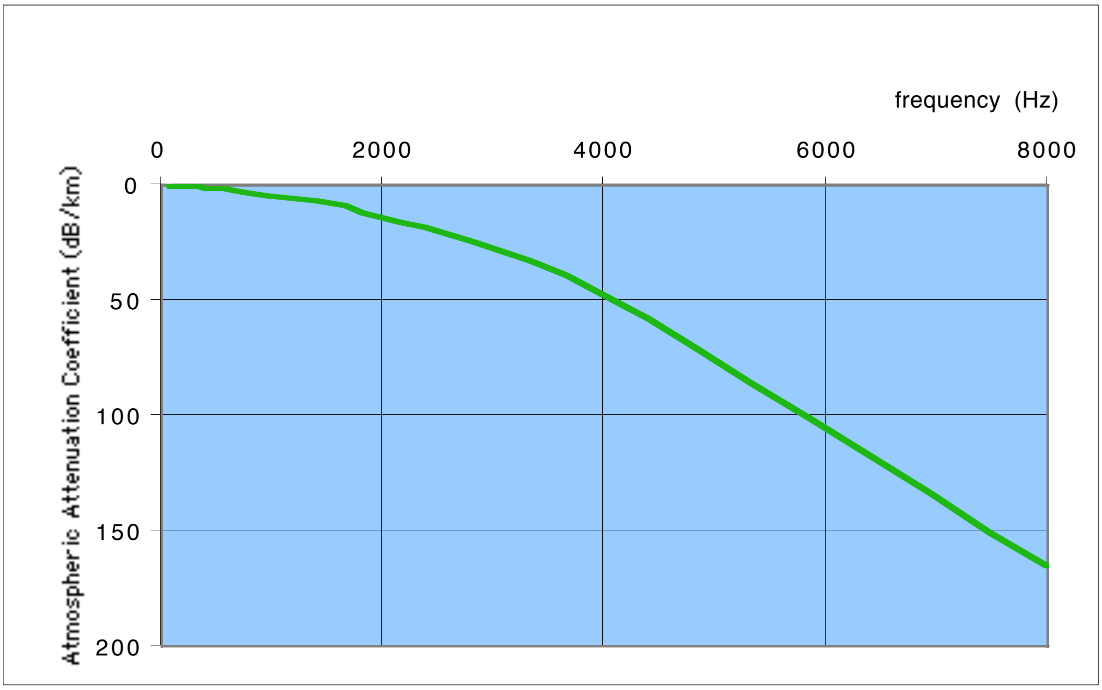



Fig. 7. Atmospheric Attenuation Coefficient (dB/km) at 20˚C, rel. hum. 30%. (see Rossi 1986).

## Acousmatic diffusion

For a long time, the techniques used for the diffusion of tape music over many speakers have consisted in a manual control from a mixing board. Sometimes, composers have written a special diffusion score containing directions for the movements of the level faders in order to send the sound to the different speakers. These speakers could be placed on stage like for Acousmonium by GRM or be placed throughout the audience.

The manual control of spatialization was possible only with monophonic or stereophonic tapes. With the development of multi-track tape recorders or computer systems this has become impossible to achieve. In the eighties, various systems were constructed with VCA block matrices. It is only recently that computers present multi-channel / multi-track diffusion systems. They need powerful DSP cards and interfaces supplied with many input and ouput connections.

Among the different commercialized systems, we have worked at the GMEM on the Sigma1 software from APBTools[12] and more recently on our spatializer built in MAX/MSP.

## Sigma1

The program Sigma1 lets the user create the movement of multiple sound sources in a group of speakers. It is a standalone application on Macintosh computers equipped with Protools TDM sound cards. It authorizes sound diffusion on up to 16 independent speakers. Sigma1 can read ProTools sessions, sound files or live input (upper limit: 32 tracks).

Working with Sigma1 consists in graphically positioning speakers on the screen, defining their directionality and diminishing curves (see next figure), then recording the sound source movements using the computer mouse or a MIDI controller in real time. A few algorithms allow the creation of automatic trajectories.

12. APBTools : www.kgw.tu-berlin.de/~y2371/SIGMA_1/.

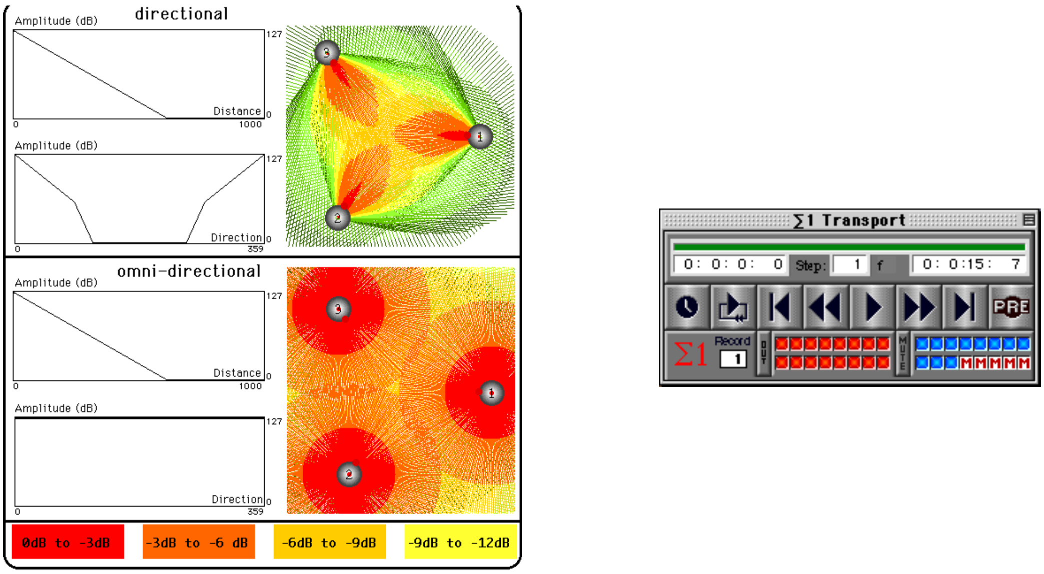



Fig. 8. Left: speaker response tables, center: curve levels of different speakers in relation to the tables, right: transport control window.

## Control of spatialization

Spatializers rarely offer sophisticated programming tools. So they have to be controlled by other programs working at an higher level. We will briefly describe some of these recent tools which make composers work on spatialization easier.

### Vect interpolations

There is a set of useful objects called Vect available on MAX software for Macintosh computers. Vect objects were written in 1993 by Adrian Lefevre. His primary goal was to create a sound spatializer commanded by MIDI controllers, by connecting a Macintosh computer to groups of VCA (Voltage Control Amplitude) controlling the sound level of various sound sources on different speakers. At Collectif&Compagnie studio from Annecy in France, Vect was controlled via MIDI by analog commands (pedals, joysticks, photo-electrical cells, etc...) using the Sami interface developed by Bernard Donzel-Gargand from Studio Forum.

Manipulating lists of data with Vect is always done smoothly, without discontinuities. "Interpolating" is the keyword; Vect VTboule object is largely inspired by the Syter machine built at the Groupe de Recherche Musicale (GRM) of the INA.

The VTboule circle interpolizer allows interpolation on 8 input vertors and gives an average vector. The interpolation is done using a few circles and a cursor moving on the plane. Each circle is defined by its position on the plane, by its radius (its size) and an associated curve. A vector is associated to each circle. A circle exerts an attraction (depending on its radius and its curve) on the cursor. The closer the cursor is to the circle, the higher the influence on the cursor, and the more present the vector associated to the circle is in the vector average.

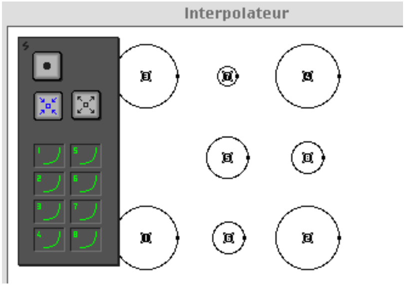



Fig. 9. A VTboule window with 8 circles of variable sizes, left : the command panel.

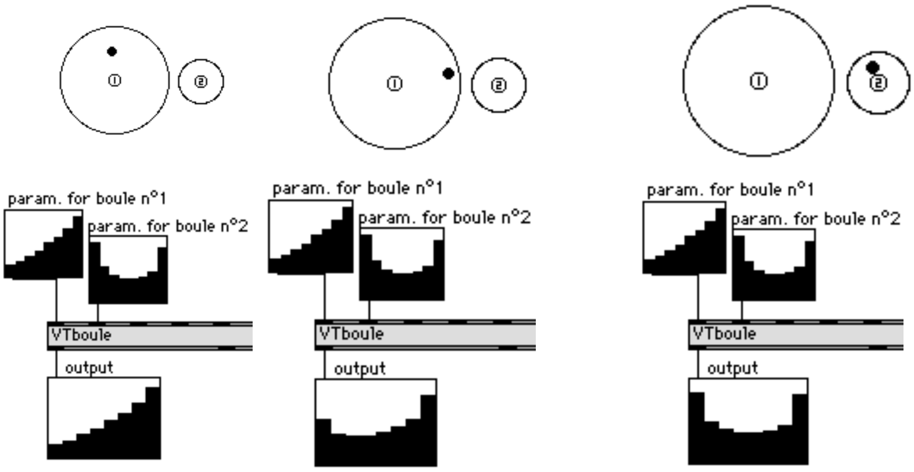



Fig. 10. Moving a cursor produces interpolated values.

In the installation called *Le Messager* (Paris, 1995), directed by Catherine Ikam and Jean-Louis Flery with sound by Jean-Baptiste Barrière (Ircam), the VTboule objects were used for controlling sound synthesis and spatialization (see Pottier, 1999). This installation consisted of a 3-D human face created by the computer and projected on a large screen and an artificial singing voice, spatialized though many speakers. An ultrasonic sensorthat people could displace in the room controlled the transformations of the face and the sound.

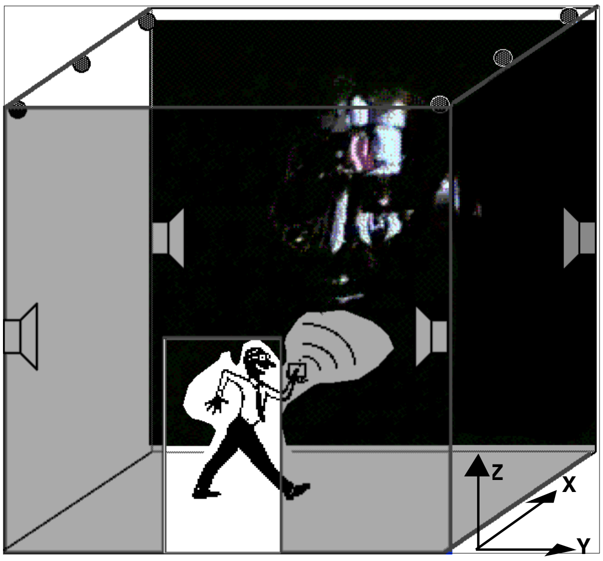



Fig. 11. *Le Messager* installation.

The sensor gave information on its position in a three dimensional space. This information arrived at a PC computer and was then transmitted to a SGI computer which produced the image. The information was then sent to a Macintosh computer and was used by MAX to control the VTboule objects, that produced parameters for the sound synthesis and spatialization which were done by a NeXT computer (SIM).

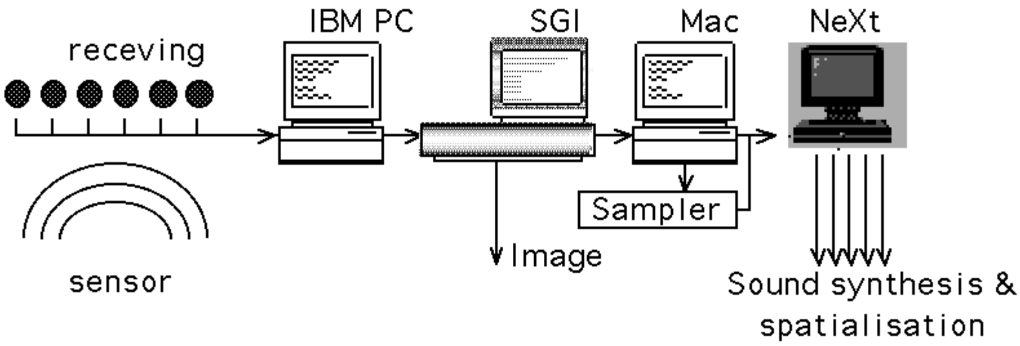



Fig. 12. The computer's connections.

The visitor had the impression that the sound followed the sensor but at some positions, the VTboule objects sent the sound to the opposite corner, creating an ambiguity as to the origin of the sound : the sensor or the face?

## The MIDISpace system

There is another spatialization control system which we would like to describe. The MIDIspace system is a graphic interface used for the control of any spatialization device. Every sound source of a musical piece can be placed on this interface as a graphic icon, as well as an object corresponding to the listener. A constraint-based mechanism allows consistency maintainance in the overall mixing. The constraints represent properties of related sound sources, which should always remain true, and may be stated by the user through the interface. When an object is moved, a constraint solver uses the constraints to propagate changes (see François Pachet and Olivier Delerue, 1998).

Fig. 13. The 2-D MIDISpace interface for specifying mixing constraints.

## Holophon

The Holophon was written at the GMEM using Common Lisp. It permits the user to draw vectorial trajectories representing the movement of several sound sources across different speakers. As well as entering and editing trajectories graphically, various algorithms can be used to generate specific trajectories.

The trajectory of each sound source can be graphically programmed by inserting a series of points which succeed each other in time on the graphic display (see next figure).

Each point determines the sound level of the source in each of these speakers in relation to its distance from the speakers and according to their orientation.

The time interval separating two points as well as the temporal resolution to cover this space can be chosen by the user for each new point.

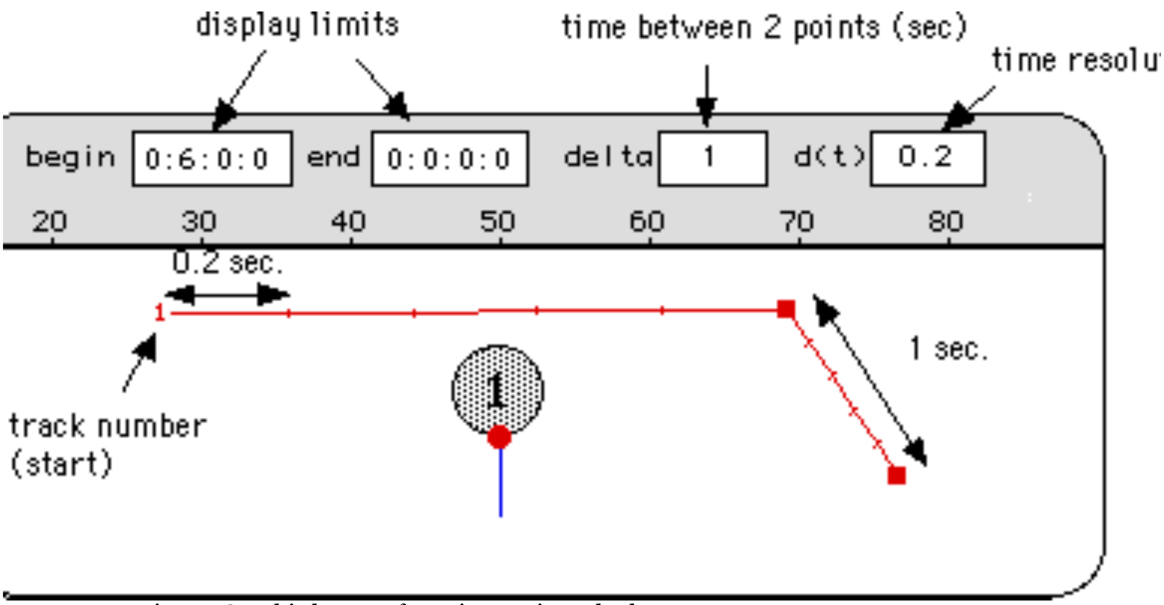



Fig. 13. Graphic layout of a trajectory in Holophon.

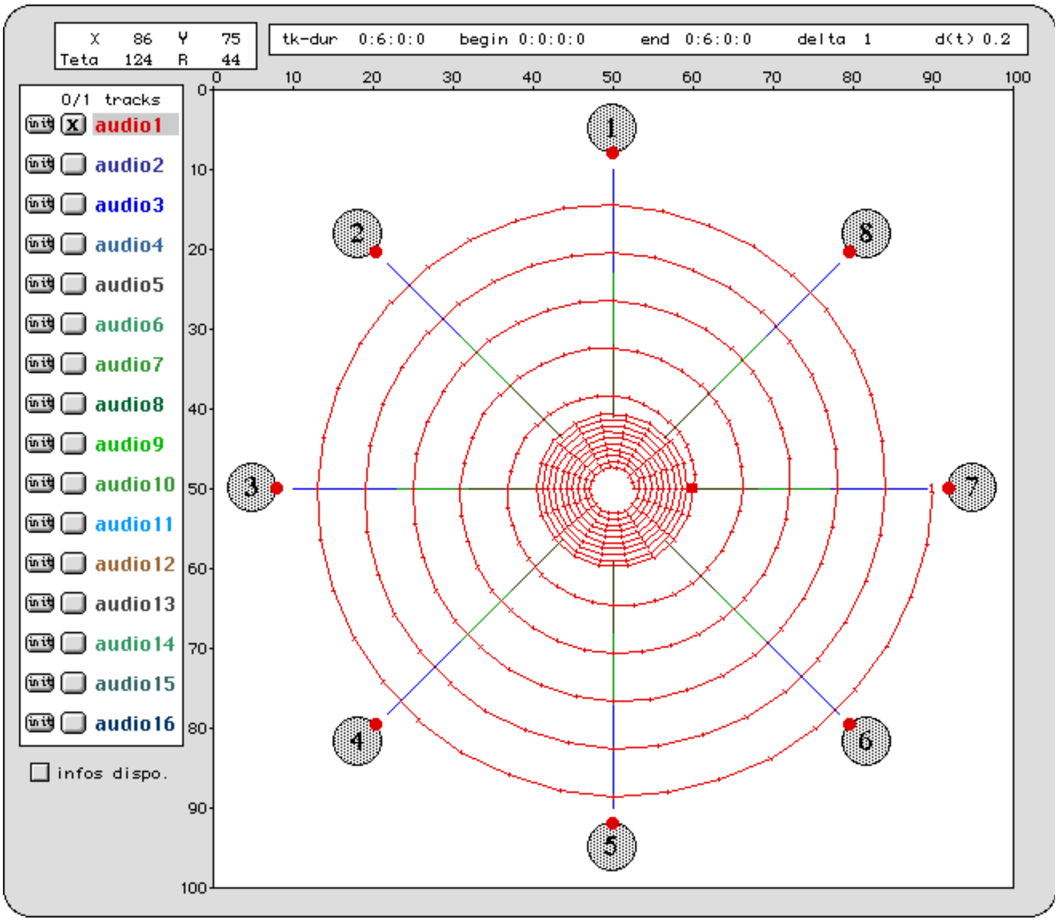



Fig. 14. Circles and spirals in Holophon.

Various functions allow the automatic programming of trajectories. Some of these allow the reproduction or the modification of the existing trajectory: duplication, translation, rotation, symmetry. Other functions construct trajectories from mathematical algorithms: rotation, spirals, oscillations, semi random displacements.

## Gestures for control

### Mixing boards

#### Hand-controlled

Typically, the gesture for controlling spatialization consists in moving volume faders on a mixing board. This method, first used by Pierre Schaeffer and Pierre Henry for the diffusion of electroacoustic music, is at the top with the Acousmonium and some similar tools but can be used only with a limited input track number (mono or stereophonic sources). Each fader controls the volume of the source in one speaker. For stereophonic sources, the faders are generally grouped by two as well as the speakers.

#### Using automation

Recently, with the development of automation, mixing boards can control more faders than a human hand can. Systems like MIDISpace (see above) can be used for grouping many faders with constraints. Moving by hand a single fader will produce coherent variations of all constrained faders. The only problem is that automated mixing boards rarely have more than two or four independent outputs.

#### Computer programming

With computers, the sound engineer or the composer can program the diffusion of multi-track sources over many speakers. With programs like Holophon (see above), this programming can be graphic (drawing trajectories) or algorithmic (programming geometric movements). Before the concert, some parameters can be easily changed in relationship to the acoustic parameters of the room.

### Other control interfaces

#### 3-D sensor

With *The Messager* installation (see above), we used a infra-red sensor for the control of the 3-D positioning of the visitor. The spatialisation of the sound was calculated in relation to this parameter.

This system allows the spatialization of the sound in relation to the physical position of an object.

#### Video sensor

At the GMEM, we have used a video camera with the VNS processor by David Rokeby[13]3 for the control of a virtual instrument. Graphical regions can be defined around the performer. Movement seen in the different regions can be used to control different parameters of sound synthesis, including spatialization.

13.See www.interlog.com/~drokeby/vnsII.html.

Fig. 16. Control of a MSP patch with a camera and a VNS processor.

## Meta-instruments

The Meta-Instrument created by Serge de Laubier is a powerful instrument for a continuous control on the spatialization or synthesis parameters (see de Laubier, 1999 and the article in this book).

Fig. 17. The Meta-instrument.

### Traditional instruments

#### Using pedals

Technology extends the possibilities of traditional acoustic instruments. The easiest way for allowing an acoustic instrument to control sound transformation is the use of pedals. Pedals can trigger a process of transformation or control the level of a transformation.

#### Using real time sound analysis

Analysis of the sound produced by the instrument in real time permits spatialization of the sound in relationship to its nature.

An example can be given with the piece *Cantus Primus* by Olivier Stalla, created by the bassist Jean-Pierre Robert in 1999 during the festival "Les Musiques" in Marseille. In the third section of this piece, the pitch of the bass, obtained by using a pitch-tracker program, controls the Y position (front to back) of the amplified sound of the bass and the pitch scale controls the X position (left to right).

The gesture control of spatialization is a problem which has many different solutions. We haven't found an universal system for this yet. Firstly, major sensors works only in two dimensions while spatialization is typically a three-dimensional problem. Secondly, it is difficult to imagine a way for one person to control many sources in the space at the same time. So logic and/or constraint algorithms can help to have global control of spatialization.

## Conclusion

The systems presented in this text are inevitably selective, but they reflect different approaches to the tools currently proposed.

Sound spatialization systems are more and more numerous. With Home Cinema, they become commonplace. Control systems for composers have increased. Composers have the feeling that this technology can bring them a new field of expression. They can explore space-time completely and they can create new sound situations, especially with movement. We now need to find effective new laws which musical sound space construction propose. We also have to find the sensors that can be used so that a performer / instrumentalist has complete control over sound spatialization.

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