THE VISUAL REPRESENTATION OF SPATIALISATION FOR COMPOSITION AND ANALYSIS

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ABSTRACT

The motivation for this text is my ongoing research into creating a uniform and comprehensive notation system for music regardless of sound sources, acoustic or electronic. I propose a way to visually represent the positions and movements of sound in composition and analysis of music which in different ways utilises space as a parameter. I address a number of aspects of spatialised music to take into account when defining a notation language for the music. I suggest visually representing the room in different ways depending on how the music relates to the concept of space: as projections from the center of a sphere for more structural work, or as coordinates in a cubic room for works that depict a physical or imagined space. I also show how these descriptions of space are integrated with my existing notation system.

1. INTRODUCTION

Though space has always been an important aspect of music it is with the development of electroacoustic music that spatialisation has become a composition parameter to be fully integrated with the compositional structure of Western music today. In his visionary text, Varèse famously spoke of sound projection becoming the fourth dimension of music [1]. However, if we consider early concepts of music, with music inseparable from dance [2], space and movement as part of the compositional structure of music is an ancient idea. Despite space becoming an increasingly important aspect of electroacoustic music composition, there is little in terms of established notation for the movements and positions of sound.

In this text, I will describe recent developments in the visual representation of spatial sound. I will discuss some concepts that I found useful to consider when deciding on the functionality of the spatialisation notation system to integrate with my existing system for analysis and composition [3]. Finally, with these concepts in mind, I will describe some of the functionality of my own solutions for visually representing spatial sound. What I need is not necessarily a complex system but rather a way of notating sounds that both my students and I will find intuitive to work with. Providing notation tools for spatialisation to composition students, will make it easier for them to formulate and structure composition ideas related to space.

2. BACKGROUND

Even if we disregard the role of dance in the historical development of music, space has always had a strong impact on this art form. The most obvious example is the influence of room acoustics over both timbre and durations. In Messiaen's *Apparition de l'Eglise éternelle* for Organ [4], the large church acoustics usually surrounding its performance make the transition from a dense dissonant chord to a consonant chord a gradual process since each chord lingers in the room long after its release on the keyboard.

When we discuss spatial aspects of music we are faced with a similar problem to that of musique concrète: how to relate to a musical parameter that, like timbre, so clearly refers to phenomena in the physical world. Annette Vande Gorne speaks of the space illusion (L'espace illusion) as a category [5] and Natasha Barrett, when discussing approaches to space in music, speaks of the illusion of a space and the allusion to a space [6]. Marije Baalman, in her text on spatial composition techniques and technologies, notes that spatialisation technologies are usually oriented towards recreating the acoustics of the physical world while composers in their spatialisation techniques are more inclined to create something new, not necessarily relying on what would be considered realistic or not [7]. A good example is how reverb units often specifically name the type of room applied to the sound in their presets even when they are made up of filters rather than recorded impulse responses from actual rooms. So a reverb preset with a long reverb tail is not thought of simply as a reverberant space of a particular size but more specifically a cathedral, suggesting that adding this effect has religious connotations.

Peters, Marentakis and McAdams find in their qualitative and quantitative analysis of spatialisation technologies and techniques that only 38 % of the surveyed electroacoustic composers use notation for spatial aspects of the music [8]. This should come as no surprise considering that a score is not really necessary for the production of electroacoustic music. In fact, that this music is not easily reduced to notation has been highlighted as a strength of the genre [9]. However, in the aforementioned survey several composers cited partly a lack of notation standard as the reason for not using notation for spatialisation [8]. There is indeed no standard, but if we imagine a connection between the notation of a musical parameter and the graphical user interface used to control the same parameter, the homogeneity of the graphical layouts of interfaces in spatialisation tools would suggest an opportunity to find a notation that should look familiar to composers working with spatialised sound. In other words, the graphical user interfaces found in tools like ambisonics panning software suggest working solutions for visually representing positions and trajectories of spatial sound layers in comprehensible ways. In existing solutions there are indeed connections between notation and the software used for rendering the spatialisation.

3. EXISTING NOTATION SOLUTIONS

While there is no standard for notation of spatial sound, there are some very interesting systems and techniques for the visual representation of space available. The earliest more widely used systems can be found in the world of dance choreography with its long history of notating movements and positions in space along a musical score. The dances in the courts of France and Italy in the 17th Century emphasised the paths of the dancers over the dance floor, giving rise to notation like the systems of Feuillet, Lorin and Landrin representing the dancers' paths as floor patterns where the dancers' body movements are traced over their trajectories in the floor space [10]. Labanotation, perhaps the most famous notation system for dance, also has symbols and methods for visually representing the floor patterns of the dancers [11]. Labanotation and its derivative, Laban Movement Analysis, have been used in various movement related research such as in Abe, Laumond, Salaris, and Levillain's application of labanotation for humanoid robot movements [12].

Many composers work with their own tailor-made solutions for spatial notation, such as Karlheinz Stockhausen's indicators for loudspeakers in the composition process of Kontakte [13] or Pierre Henry's solution in the realisation score of Messiaen's Timbres-Durées [14] where different tape tracks have their own specified spatial identity. I have also throughout the years seen many interesting solutions from my students coping with representing spatial data on paper.

In terms of current research during the last five years there have been some interesting advances in the field of spatial sound notation, all related to technologies for sound projection:

3.1 SVG to OSC Transcoding

Starting from the idea that electroacoustic music is not usually notated but rendered, Rama Gottfried suggests working with graphical software like Adobe's *Illustrator* to create graphical scores with maximum flexibility. The scores are then output as Scalable Vector Graphics (SVG) to be interpreted as OSC to control sound e.g. in Max [15].

The advantages of this system is that there is little compromise in terms of the quality and possibilities of the graphical output, while the data exchange format itself is readable and possible to understand. Also, thanks to XML's tree structure model one can create hierarchies of graphic objects [15]. While I will not go into more detail regarding this solution in this text, this system should be of great interests to composers who continue to rely on their own systems of representation for their work.

3.2 SSMN and the Taxonomy and Notation of Spatialisation

To my knowledge, the most detailed symbolic notation system for spatial sound developed so far is the *Spatialisation Symbolic Music Notation* (SSMN) system from ICST in Zürich. The system builds on a taxonomy of spatialisation that takes into account the different uses and needs from composers working with spatialisation today [16].

The system is based on room descriptors and descriptors of sound sources with their own symbols. The descriptors can have assigned properties such as numeric parameters, trajectories, names and flags for more detail, e.g. when using the system to control the dedicated spatialisation engine for panning over a multi-speaker system using ambisonics. For the first case studies, a version of open source notation software *MuseScore* [1] was modified to handle the notation as well as OSC communication, not otherwise part of the software's functionality.[17]

3.3 SPAT-SCENE

Garcia, Carpentier and Bresson relied on interviews and studies of score drafts of eight composers working with spatial sound to develop new functionality for spatialisation in OpenMusic with focus on aspects such as the possibility of graphical and gestural input, notation and time management for control of the spatial rendering [18].

One key problem they address is the difficulty of defining the temporal aspects of trajectories in the compositional process. Their solution, *SPAT-SCENE*, is a graphical user interface for the spatialisation engine *Spat* [2] in OpenMusic [3] [18]. The visual representation can then be exported as SVG for import in notation software.

3.4 About These Solutions

The SVG to OSC transcoding concept meets the ever present need for composers to feel completely free to go their own ways with their notation and still be able to apply the results to current digital audio projection tools. SSMN meets the need for standardised notation symbols for spatialisation. This is valuable for composition and perhaps even more so for analysis. By subjecting different works to a common notation system, it is possible to analyse and compare works on a deeper level than if the works have different tailor-made systems for the visual representation of their spatial aspects. SPAT-SCENE is not a system of symbolic notation like SSMN, but it caters to the specific needs of electroacoustic composers with regard to input of spatial trajectories, temporal control of the composition,

[1] https://musescore.com
[2] https://forumnet.ircam.fr/product/spat-en/
[3] http://repmus.ircam.fr/openmusic/home

the rendering of the spatialised sound in Spat and the notation possibilities. See Figure 1 for a comparison how trajectories can be visually represented by SSMN and SPAT-SCENE, bearing in mind that both systems are highly flexible and the output of both systems can look quite different depending on how you work with these tools.

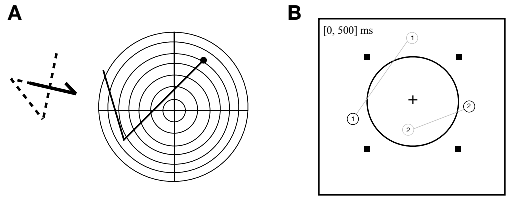

Figure 1: Examples of the kind of displays that can be used in the SSMN system (A) and SPAT-SCENE (B) for visually representing trajectories of sound sources.

4. ASPECTS OF THE VISUAL REPRESENTATION OF SPACE

4.1 Perspective

A major difference between dance notation and spatialisation notation is that of perspective. At the heart of labanotation is the movement of one's body. Composers and music software, on the other hand, relate movement to an ideal listener position, the sweet spot. I believe it would be helpful for the notation of spatial sound to include the possibility of multiple perspectives in the visual representation of music. Just like the dance choreographer must think of what each individual dancer is doing while maintaining control of the overall scene it would make sense to visually represent both the individual movements of sounds while also displaying the composite scene image with all sound layers and components in one frame. For the individual sound layer, we're interested in the start, execution and completion of each individual movement, while the composite image of all movements will help us keep track of how the individual movements affect the overall sound image in each instance. This is important particularly with regard to the concept of balance.

4.2 Balance

One important reason for the need for including a composite image is to keep track of the balance of the spatial audio image. In stereo mixing, maintaining an overall left-right balance is paramount. A recording that as a whole tilts to the left would be considered a mistake. This is also reflected in our behaviour as listeners. If a part of an acoustic concert is performed on the far left side of the stage we turn to face the musician not only to see the performance but also to "balance" the stereo image of our listening experience. In stereo recordings, instruments panned to the left are usually complemented by an equivalent instrument to the right – we can imagine a kind of spatial counterpoint theory where sound appearing on one side of the audio image is commonly complemented with an equal sound on the other side.

The balance of the left-right stereo field is in a way easy to comprehend since the left and right sides of the audio image are equal to our ears. Front-back and up-down shifts are more complicated relationships in terms of balance, since shifts in these fields have hierarchical consequences: A sound right in front of us has greater significance than a similar sound of equal loudness and distance from the rear. Similarly I would argue that a sound in the same height as our ears seems more urgent than something from below or above. While this should be visually apparent by simply looking at the shape of our outer ears, this could also be reflected in the visualisation of the notated composite image both for 2D and 3D displays of the listening field. The notation can otherwise fool the composer into believing that all panning angles are equal. Obviously, for installations and other works without the audience firmly positioned in one direction such a notational feature would not be needed.

4.3 Room and Resonance

Different reverbs with different decay settings on the same recording at the same time is common in stereo mixing today. Also, placing different reverbs in different sets of loudspeaker pairs to simulate the opening of a room inside the room is a suggested spatial technique in Roads and Strawn's Computer Music Tutorial [19]. But when defining the resonance of a sound source for notation it's important to remember that for acoustic music each instrument body is also a small room inside the room acting as a resonating chamber for whatever air or string that has been put in vibration. Since most electric instruments don't have resonating bodies [4] , reverbs are sometimes added not to act as the musical space but as the resonating body of the instrument. There is a reason why a guitar amplifier has its own dedicated mono reverb - without it the guitar risks sounding muted and will not match the sound of any acoustic instruments of the ensemble. Accordingly, the visual representation of reverberation or other resonators should specify whether the effect is that of a resonating body for an individual sound source or as the musical space of the music. There is a grey area here since loud cathedral reverbs are sometimes used as inserts on a single sound source. Also, there are cases when reverb effects act like a synthesis technique rather than a room and should therefore be notated as timbre rather than space–the echo chamber sounds of Stockhausen's *Studie II* is a good example of this [20]. Electroacoustic music is also interesting with regard to the problem of room and resonance in that while electronic music has tone generators that produce sound with no resonating rooms or resonators, the sound material of musique concrète may include both already from start in its material. This of course relfects the contrasting nature of the two fields in terms of their relations to their material.

4.4 Sound or Action

In the existing systems exemplified above, the notation of action and result is one and the same thing, i.e. the nota-

[4] The ondes martenot is a lovely exception

tion also controls the spatialisation rendering. But for the sake of individual sounds and/or performers moving along individual trajectories it can be necessary to extrapolate individual instructions in a way that makes sense for that sound/performer. This has been put to the test in a case study involving the SSMN system where spatial notation was assigned to different performers moving loudspeakers [17]. While the movement of people rhather than sound is not very common, some composers have put this ideas to good use, as in Benedict Mason's 2008 piece *Music for Moderna Museet* [21], where he relied on individual map fragments of the museum building on cards for the individual orchestral members to know where to move during the performance. Also, in performances of Rebecca Saunders' installation piece *Chroma* [22], positions and movements of musicians and audience is a part of the experience.

4.5 Imagined or Projected Space

Methods for panning sound in software and hardware place the sound sources at the centre of the listening space by default, and to position the sound somewhere else means specifically projecting the sound at a position in the possible listening field defined by the loudspeaker system, e.g. in ambisonics panning software, positions are defined by their horizontal (azimuth) and vertical (elevation) angles and their distances from the listener. For much spatialisation work this is practical both from a conceptual and practical viewpoint.

But for compositions where sound objects are imagined and positioned in a physical or imaginary space, when sound objects or indeed musicians are moving across the room, we're dealing with a different kind of spatialisation where each object is not necessarily best defined by its position in relation to the centre. The difference between these approaches is similar to that of Vande Gorne's categories *geometric space* and *illusory space* [5] where the former denotes spatialisation from a structural point of view. One could argue that, from a notational viewpoint, this is a superficial difference considering the fact that values can easily be converted between angles and distances and room coordinates. But if the reason for visually representing the spatial sounds is for us to make sense of a particular composition for the sake of analysis or composition this is an important conceptual difference.

4.6 Distance or Amplitude

When we encounter acoustic sound sources in our surroundings, the difference between dynamics and distance is often evident thanks to our knowledge of how sound loses energy with distance and how sound sources change at low and high sound levels respectively. But for acousmatic music the difference may not be obvious. We are not necessarily familiar with the sounds presented, and even if we are familiar with the sounds, they do not necessarily act as acoustic sources of sound at different volume levels or distances. This becomes a problem for credible three-dimensional panning with respect to distance [23]. And for the purpose of analysing or transcribing acousmatic music we have to rely on our perception to decide when amplitude changes are related to distance.

4.7 Articulation or Change of Position

When defining and notating movements of sound it makes sense to adapt the same approach as with the notation of traditional musical parameters such as pitch and dynamics: Just like there's a structural difference between a vibrato and a glissando or between a tremolo and a crescendo when writing for voices and instruments, there's a difference between sounds that are articulated through movement patterns such as continuous rotation and autopanning, and sounds moving from one position to another. It is the difference between articulation and a change of position. Even for a heavy vibrato from a singer you won't expect this to be reflected in the sheet music since the pitch from a structural point of view is considered to stay the same regardless of the articulation. (See [24] for a discussion on such notation discrepancies.) Likewise, a sound rotating around the listener can be thought of as a sound in orbit rather than a repositioning of the sound from one place to the other. This should be reflected in the notation.

4.8 The Problem of 3D Represented on Paper

A major problem of visually representing spatial sound as printable notation is the fact that music notation, as well as audio editors, tend to favour one dimensional parameters to be plotted over a time line. This works for displaying simple left-right panning, but adding another dimension for front-back positioning immediately complicates things, not to mention the problem of displaying movement in a 3D space. Many use top view 2D symbols placed above or below the staff, as in the case of both SPAT-SCENE and SSMN which relies on radar style displays as specifiers for descriptor symbols like the *bezier* symbol [17]. But to add further dimensions we may need to consider going beyond spatial dimensions and e.g. incorporate darkness-brightness differences or colour saturation.

5. MY NOTATION SOLUTIONS

The purpose of this text is not in any way to disprove previous research or show how the systems cited here fail in any regard. Also, those systems have possibilities not covered here because they are beyond the scope of this paper. My major concern when formulating my own solutions is to find notation methods that are easy to grasp so that composition students with little or no experience with electroacoustic music will be able to start working with the notation and achieve their desired results. But in order for the system to be of any interest for the students the system must also be versatile and open for custom solutions.

When deciding what spatialisation notation to go with my overall notation system for composition and analysis, as with the previous work [25][3], I'm more interested in finding existing working solutions as starting points rather than inventing a new system from scratch. Of the three existing solutions briefly presented above it is a combination

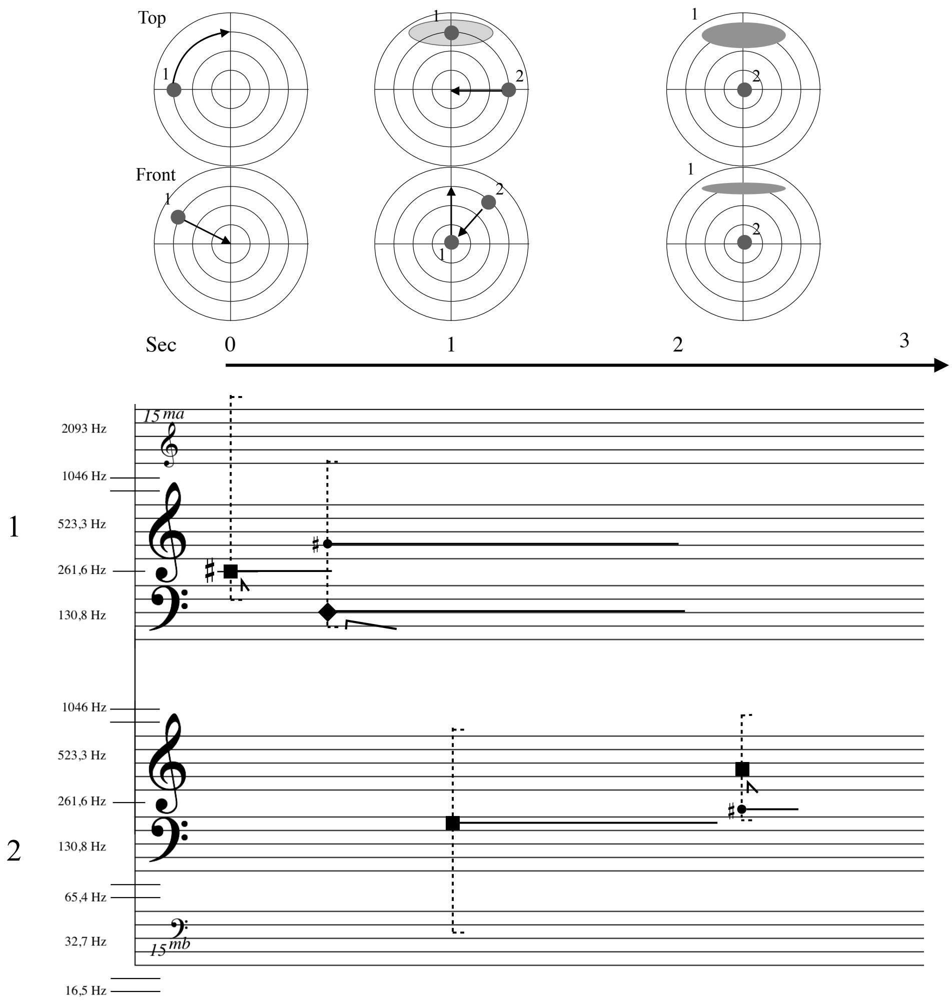

Figure 2: Example of composite displays of positions and movements for staves 1 and 2. In this case, the ambisonics style sphere indicators where used. The second indicator displays a widening of the field occupied by the sound of staff 1, which has happened by the time of the third indicator.

of the SSMN and the SPAT-SCENE that I find most suitable for my purposes. The SVG to OSC solution I find to be more useful for composers who define their own systems and symbols as they go, which remains an important part of electroacoustic music creation among composers [8]. What I will propose therefore is the following:

5.1 Composite Displays of the Sound Image

For key moments or continuously, depending on the composer's wishes, there will be frames that, just like the graphic output of SPAT-SCENE, indicate all sounds' positions at the time. This is particularly important for analysis and composition when exploring or working with the development of the sound image as a whole. For each sound layer indicated their position and their immediate plans for moving and/or changing size and definition are displayed.

It is important how this composite image is displayed and in what format the positions and movements are conveyed. Bearing in mind the discussion of sound projection versus room description above, I introduce the possibility to select one or the other depending on the focus of the music. When visually representing experimental and structural work on spatialisation in works aimed for ambisonics rendering, circular indicators from top view and front view would be used (see Figure 3 A). Positions would then be indicated in the style of ambisonics panning using AED values (Azimuth, Elevation and Distance). On the other hand, pieces that work like a kind of sound choreography, where the physical or imagined positions in the room are in focus, a square-shaped grid would be used to display room positions and values would be indicated using cartesian coordinates (see Figure 3). The need for these two perspectives is of course not a new idea and technologies used for spatialisation often provide both types of displays.

Regarding perspective, both systems would rely on a 0 point in the middle, but while the circular sound projection oriented system, through its design, has a very obvious "bulls eye" center, the cartesian grid style display has a mere "+" sign to indicate the (0,0) coordinates of the image.

In Figure 3 only the first display has a front view below

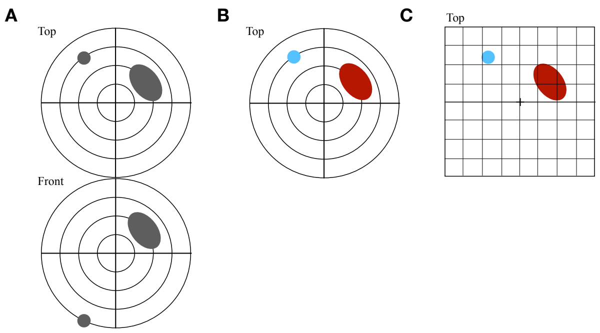

Figure 3: Examples of my solution for visually representing the composite information on positions and movements of the sound layers in the score. Examples A and B are aimed for a sound projection focus, relying on AED (angles and distance) while C is focused on the illusion of the room created by the spatialisation, relying on XYZ (cartesian coordinates). For B and C the elevation of the sound is indicates with a colour scale instead of a separate front view display. From dark to bright red means sounds are moving up from ear level, and from dark to bright blue means sounds are moving down from ear level. The indicator with the smaller size has a more clearly defined position in space, while the larger indicator suggests occupying a larger area of the listening space

to indicate elevation. This is because examples B and C both rely on colour to display elevation or height. I was inspired by the cross-modal correspondence between colour and temperature [26] for selecting red for high positions and blue for low positions. Brighter red indicators suggest sound sources higher up, while brighter blue suggests sound sources lower down. The darker they get, they move closer to ear level. This colour scheme may be subject to change following the case studies with students. An alternative selection of colours could be the ones used in altitude meters on airplanes, where blue represents the sky and brown represents the ground.

5.2 Notating movements

Much advanced spatialisation relies on the programming of trajectories, which is not only a problem to display but also to input in an intuitive way for a rendering engine to understand. For SPAT-SCENE they have introduced an application for mobile devices for tactile trajectory input [27]. To visually represent these movements they show initial positions and target positions over an indicated time interval, while for SSMN there is first the fixed descriptor symbol to indicate type of movement, and then optionally a radar style display to show the specific movement to be performed until the next indicator. Both systems are straight forward and I chose a very similar approach, though unlike SSMN I do not use a separate indicator to define type of movement. See Figure 2 for an example of indicators connected to a short score of four sound objects, notated on two separate staves, one staff for each spatialised musical layer.

5.3 Spatialisation as articulation

In my notation of sound objects, inspired by symbols and ideas from Lasse Thoresen's spectromorphological analysis [28], there's the possibility to notate various paramtetric changes as articulations by providing the appropriate symbols below the main sound object symbol (a circle, square or diamond note head). As with traditional notations of articulation, this should be used for changes that don't appear on a structural level but that provide a certain identity to a particular sound object, like a vibrato or a tremolo. See Figure 4 for example of how modulation is notated in my system. Basic sawtooth waves are indicated here to achieve regular clockwise or anticlockwise rotation. Width and frequency can be added for a more detailed indication. The colon marks after the sawtooth symbols in Figure 4 signify repetition, but one can also define spatial articulations that, like accent marks in traditional music, are carried out only once. If the colon mark in example A of Figure 4 was removed, the corresponding sound object would be expected to complete one rotation during the course of its duration.

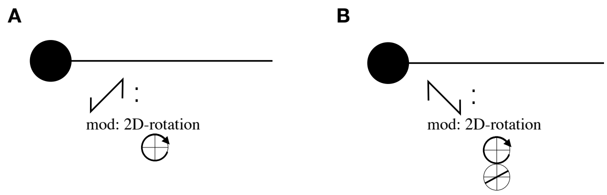

Figure 4: Simple spatialisation attributes notated as articulations of a sound object. Both examples A and B are two-dimentional rotations but example A is a clockwise rotation while example B is a tilted anti-clockwise rotation in a three-dimensional field.

5.4 Room, resonance and reverbs

As mentioned above, for notating the presence of a resonant room or chamber, I suggest first deciding whether it is to be considered *the* space of the music, a space of the music or a resonating room or body for one particular sound or sound layer. For a reverb or a room caught on tape that remains static, there's no reason for continuous notation, only a text or a drawing in the beginning of the score. But for an evolving space, a separate staff line would do for whatever changes that appear. For effects only affecting a particular sound or layer, as in the case of a reverb acting as the resonating body of a sound, these should be notated as a shadow on the extension line of the sound object to indicate the extent of the effect (see Figure 5).

6. CONCLUSIVE REMARKS

In this text I have conveyed my ideas for moving forward with the notation of spatial sound for the purpose of analysis and composition of acoustic and electroacoustic music. The ideas will be put to the test already during the academic year 2019 to 2020, when composition students will

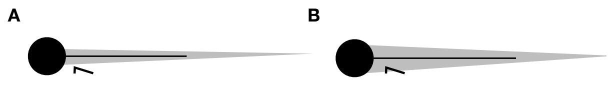

Figure 5: Reverb effects added to specific sound objects, notated as shadows behind the extension lines. Example A shows a softer effect while B is a louder effect.

work with the notation in case studies aimed at exploring new possibilities for teaching composition, analysis and ear training with the notation of sound in focus. Thanks to the establishment of concert halls with large speaker sets for reproducing high-quality three-dimensional sound, there is in the field of electroacoustic music a renewed interest in tools that enable the continued exploration of spatialised sound.

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