TAXONOMY AND NOTATION OF SPATIALIZATION

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ABSTRACT

The SSMN Spatial Taxonomy and its symbols libraries, which are the corner stone of the Spatialization Symbolic Music Notation (SSMN) project, emanates from research into composers' attitudes in this domain. It was conceived as the basis for the development of dedicated notation and rendering tools within the SSMN project.

The taxonomy is a systematic representation of all relevant features necessary to specify sound spatiality: shape and acoustic quality of the space, structure, position and movement of sound sources. It is based on single descriptors that can be combined in order to define complex spatial configurations. Descriptors can be transformed locally and globally and can be the object of structural and behavioral operations. The SSMN Spatial Taxonomy proposes a corresponding graphic symbolic representation of descriptors, operations and other functional elements facilitating the communication of creative ideas to performers and technical assistants.

This paper focuses on the presentation of the taxonomy and the symbols. Additionally it describes the workflow proposed for using symbols inside a notation software prototype developed within the project. Finally, further aspects concerning the actual and future developments of SSMN are mentioned.

1. INTRODUCTION

The field of sound representation has undergone continual development throughout the history of creative arts. The issue of sound motion representation, as concerns composers, has however hardly been studied. Composers have been continually obliged to reinvent strategies for communicating their ideas of spatial movement of sound, performers' displacement, and description of the performance space. In fact, even today's musical software tools that include implementation of spatialization have been limited in their capacity to propose adequate notation possibilities to convey spatial information within musical scores. In spite of the availability of a variety of strategies and tools for spatialization within the context of electroacoustic music composition, decisions about position and movement of sound in space, or the general question of virtual space quality remain often a secondary formal issue; in many cases these decisions are left to a post-production stage instead of being fully integrated throughout the composition process. This situation can marginalize spatialization to an ornamental aspect that can be adapted or reduced without affecting musical substance.

On the other hand, performers engaged in the interpretation of music involving electroacoustic spatialization (and other kinds of signal processing) find mostly a reduced graphic representation of the ongoing processes in the score [1]. According to the experience of the authors during several years of performance practice the notation of electroacoustic events prioritize mostly cue numbers and synchronization events. This limits the possibility of a more intimate interaction within the performance situation. In addition, the lack of a spatialized acoustic feedback while studying prevents performers from preparing a piece taking into account sound motion. This issue becomes especially relevant when considering the usual restrictions of rehearsal time in performance spaces.

The need for a graphical representation of spatialization within the context of sound diffusion of electroacoustic music in concert has been also addressed with arguments pro [2] and contra [3]. Nevertheless a generic and practical way to accurately notate spatialization has not been formulated yet. Even meticulous spatial notation as in Stockhausen's *Oktophonie* [4] using sequences of channel numbers instead of symbols –as in the introductory notes to the score– is difficult to read for performers.

Finally, when audio engineers collaborate with composers preparing compositions within a multi-channel environment, they have to overcome the difficulties of interpreting placement of sound in space as imagined by the composers, who typically invent a personal system of graphical or textual explanations.

The aim of SSNM is thus to open a new approach of substantial integration of spatial relationships and spatial processes in musical thinking as well as in composition, rehearsal and performance practice. For this purpose SSMN has defined a typology of spatial movements and designed a library of symbols to represent them. In order to enable its use in creative processes, an open source software tool that integrates this library within a common western musical notation context is being developed, allowing editing and acoustic feedback through a rendering engine. Composers are thus able to use and edit symbols describing spatialization in a notation program and immediately hear the results. Performers are given full information on spatialization in the score and can hear the results from the beginning of the studying process.

2. SCOPE OF RESEARCH

During the preparatory stages of the SSMN Spatial Taxonomy, research has focused on the following:

- Musical scores containing verbal or graphical annotations of spatial indications, focusing on spatialization and extended notation in contemporary music since 1950 [5]
- Artistic performance practice wherein spatial placement and/or mobility of live performers is relevant to musical compositions as well as composers' means of expressing placement and/or motion in space [6], [7]
- Spatialization in electroacoustic media [8]
- Extended musical notation [9]
- 2D and 3D symbolic notation [1]
- Typologies of spatial qualities of sound [10]
- Spatial perception of sound placement, sound motion and physical space [11]
- Semiotics and epistemology of notation [12]
- Relevant programming languages, audio and graphic design software including Csound, PD, Iannix, SuperCollider, Max/MSP, Illustrator, WFS [13] [14], Ambisonics, IRCAM's OpenMusic [15] & Antescofo [16], *inScore* [17]
- Spatial notation in other fields, especially dance, aeronautics, geographical migration patterns, and theater staging [18]

In a nutshell, the specifications for the SSMN research project are based on a four-pronged study: (a) spatial typo-morphology resulting in the SSMN Spatial Taxonomy, (b) design of symbols, (c) integration of symbols and trajectory editing in notation software, (d) integration of notation software in a rendering engine. So far, an introduction to the project was first presented at ISMC|SMC2014 [19] followed by a poster presentation at TENOR 2015 [20].

Concerning the specific issue of a spatial taxonomy the contributions referred to above present important ideas but are limited in the sense that they were developed in view of specific aspects and purposes different from those of notation. Trochimczyk's [10] classification of spatial designs comes closer to our needs but is consciously limited to certain instrumental setups; Smalley focuses mainly on spectral structure [21] or develops a perceptual approach to the analysis of acoustic scenes [22]; Vandergorne's spatial categories and figures are specifically concerned with sound diffusion [8]; UST (Unités Sémiotiques Temporelles) [23] are obviously focused on temporal meaning. In our opinion, a taxonomy for notation of spatialization should ideally be universal, generic and based on low-level structural features that can be represented through symbols. The terminology should emanate directly from musical practice and be as much as possible self-explaining. The work presented in the next section was developed under these premises.

3. TAXONOMY

3.1 Preliminary considerations

The basic units of the SSMN spatial taxonomy are called *descriptors*. There are two kinds of descriptors: room descriptors and descriptors of sound sources. Sound sources can be physical root sound (RS) like instruments and voices or projected audio signals (PA) like microphone signals, audio files and streamed audio.

Descriptors can be simple or compound and are assumed to be perceptually relevant, but definitive perception depends on the interaction between the actual sound and the actual spatial configuration. Although descriptors are primarily defined in structural (geometrical, mathematical, acoustical) terms, they have been conceived in view of musical practice.

Simple descriptors are the basic atoms of the SSMN spatial taxonomy. They are able to denote all single primary features relevant to sound spatiality and can be represented as symbols. Compound descriptors are arrays of simple descriptors. They are used to represent more complex spatial configurations and processes (e.g. patterns, figures, motives, etc.) and can also be represented as symbols.

Descriptors can have several properties that are finally defined through names, numeric parameters and flags. For instance, the descriptor "Position of loudspeakers" has the entry "labels" to name specific items, the parameters "position" given as Cartesian or spherical coordinates and "inclination" (yaw) defined as angle and the flag "interior" or "exterior" according to their position inside or outside the room. For reasons of clarity, parameter units as well as some parameters and flags will be omitted in this paper.

The third part of the taxonomy is dedicated to *operations,* also called *modifiers*. They can be used to transform elements previously defined using single or compound descriptors or to generate new elements. For instance, the basic structural operation "Scaling" can be used to multiply a given parameter or group of parameters by a certain factor, "Repetition" to repeat a compound trajectory previously made out of single segments as straight lines and curves. *Global operations* can be used to generate relationships between complex unities like sequences and superpositions of existing compound trajectories. *Cross-domain interactions* can be used to rule relationships between spatial audio information and other media like synchronization with visual or choreographic sequences.

Finally, *behavioral relationships* like "co-incidence" or "attraction" inspired by social and biological movement patterns and observed in other contexts (see 3.3) could help to envision a new paradigm of sound spatiality based on processes rather than geometrical or visual structures. This aspect is not fully integrated in the taxonomy yet and suggests a promising research direction.

As mentioned above, the SSMN spatial taxonomy is intended to become universal and generic. At the moment not all descriptors have been defined as symbols and not all symbols have been implemented within the software prototype.

Although the taxonomy describes and classifies sound in a three-dimensional space, some objects and symbols are, for practical reasons (mainly rendering, and dependence on existing standardized formats), represented in two dimensions.

All projected audio can be subjected to speed, acceleration and the Doppler effect. Simple trajectories can be followed in two opposite directions.

After considering the wide number of possible curve types only a small number of them was explicitly addressed in the taxonomy. A detailed evaluation of their perceptual relevance remains to be done.

While sound sources can easily be defined as "points" or "groups", a concept such as "sound plane" is an abstraction of visual forms often used by composers but difficult to define in purely acoustical terms. We have nevertheless integrated it into the taxonomy.

The following section presents the complete work as an almost self-explaining, structured list of descriptors and operations. Explanatory comments are provided in brackets. Behavioral relationships will be discussed separately.

3.2 Descriptors and operations

I. Room descriptors

A. Disposition

1. Shape of the room (generic shapes)
    - a. Cube
      length, width, height
    - b. Hemisphere
      diameter, height
    - c. Church (cross form)
      length, width, height
    - d. Other shapes
      dimensions
2. Placement of performers, objects and audience
    - a. Fixed
      label, position
    - b. Variable
        - i. Line
          start/end, speed
        - ii. Arc
          start/end, curvature, speed
        - iii. Other (e.g. random, choreography)
3. Position of Microphones
    - a. Referred to an instrument
      name of instrument
    - b. Referred to the space
      label, *position*, *inclination*
    - c. Referred to specific movements (e.g. swinging microphone)
4. Position of loudspeakers
    - a. Fixed
      label, position, direction, inclination
    - b. Variable (mechanic or human driven)
        - i. Line
          start/end, speed
        - ii. Arc
          start/end, curvature, speed
        - iii. Pendular motion
          length, initial height, direction
        - iv. Other (e.g. choreography)

B. Spatial quality of the room

1. Space definition
    - a. Open
    - b. Closed
    - c. Virtual
2. Reverberation
    - a. Interaction source-room
      energy of first reflections related to direct sound, energy of late reverberation, decay time of primary reflections
    - b. Room perception (related to late reflections):
      decay time, heaviness (change of decay time of low frequencies)*, "liveness"* (change in decay time of high frequencies)

II. Descriptors of sound sources

A. Types of sound sources

1. Sound points
    - a. Physical root sound (RS)
      label
    - b. Projected audio signal (PA)
      label
2. Groups
   => Definition: A group is a collection of sound points with common spatial features. A group is defined by a perimeter wherein the single elements can be found. Position and movement of single elements within the perimeter can be defined in the same way as single points.
    - a. Root sound
      label, number of sources, position of reference point
    - b. Projected audio
      label, number of sources, position of reference point

3. Planes (PA)
=> Definition: a plane is a homogenous sound spread out in space.
label, *shape*

B. Spatial quality of single sources

1. Perceived distance (PA)
presence, brilliance, warmth (equalization)

C. Dimension of single sources

2. Scale
=> PA, perception of «bigger or smaller» than real sound source)
scale factor

D. Localization of sound sources

1. Localization of single points (PA, RS)
position, direction, inclination, aperture (PA)

2. Localization of groups
shape, *geometrical center, position of each element, within the shape*

3. Localization of planes
position, direction, inclination

E. Simple trajectories of sound points, groups or planes

1. Linear

a. Straight
start/end

b. Polyline (open)
segments, start/end

c. Poly_closed (closed polyline)
segments, start/end

2. Circular

a. Circle
center point, radius, start/end angle, direction

b. Slinky (named after the toy invented 1945 by Richard James)
start/end center point, radius, start/end angle, direction

c. Spiral
start/end center point, start/end radius, start/end angle, number of rotations

3. Curve

a. Bézier
start/end, control points, reiterations

b. Bézier_spline
start/end, control points, reiterations

c. Béziergon (closed Bézier curve)
start/end, control points, reiterations

d. Bernoulli (lemniscate)
start/end, control points, reiterations

e. Other (e.g. Lissajoux, etc.)

F. Compound trajectories

1. Compound using simple trajectories

2. Generic polygons (selection of basic shapes)

3. Free hand using interface

III. Operations (transformation or generation of new trajectories from preexistent single or compound trajectories)

A. Structural operations and modifiers

1. Operations on single sound sources, groups and planes (position); on simple or compound trajectories

a. Repetition
number of reiterations

b. Scaling
factor

c. Shift
value

d. Rotation
roll, yaw, pitch

e. Mirror (inversion)
mirror flag

f. Reverse (crab)
reverse flag

g. Palindrome (returns to the starting value)
palindrome flag

h. Random
random parameter

i. Signals as modifiers

i. Sinus
frequency, amplitude, phase

ii. Triangle
frequency, amplitude, phase

iii. Square
frequency, amplitude, phase

iv. Saw
frequency, amplitude, phase

v. Other

j. Simple or compound trajectories as modifiers
label

2. Operations on compound structures

a. Sequencing

b. Permutation

c. Interpolation (morphing)

3. Algorithmic defined functions based on externals
algo (label)

B. Global operations

1. Global scaling (space, time)

a. Linear

b. Non-linear

2. Sequence (Horizontal)

a. Loop

b. Cross

c. Tight

d. Pause

3. Superposition (Vertical)
    1. Synchronous start
    b. Delay
    c. Synchronous end

C. Cross-domain interaction
  1. Scaling (time)
  2. Synchronous start
  3. Delay
  4. Synchronous end

3.3 Further Taxonomy directions

Since the primary intention of the SSMN project is to provide a working prototype of a software package that can be tested by composers, each aspect of the taxonomy that has been addressed here undergoes verification by users. As indicated earlier, an open source score editor (MuseScore) has been targeted for graphic symbols implementation allowing real-time OSC messages to be transmitted to a rendering engine. The sound projection tool used for these experiments is an ambisonics spatialization system allowing the simulation of different multi-channel projections in various formats as well as a binaural headphone version. The score editor is dubbed MuseScoreSSMN and sends all OSC spatialization information via a dedicated port to Max-based tools (e.g. the SSMN-Rendering-Engine) [19].

While the prototype is being prepared, tested and documented, further aspects that could be symbolized are being oriented towards questions of behavioral interactions between two or more sound sources affecting their spatial movement. A research project at the University of Zurich concerning data mining and visual analysis of movement patterns proposes a taxonomy of movement patterns [18] that can be investigated using sound sources and can be integrated into the spatial taxonomy. The following list of behavioral attributes and relationships make reference to this work (page numbers) and are presented here as a suggestion for further research:

A. Behavioral attributes
  1. Trend-setter: a sound source establishing movement patterns followed by other sources, p. 10
  2. Follower, p. 10
  3. Indifferent: autonomous (non-uniform) or random movement within a behavioral context. See also: «dispersion»: "non-uniform or random motion, opposite to concurrence", p. 8

B. Behavioral relationships
  1. Imitation: see also «concurrence»: "same values of motion attributes at a certain instant or duration", e.g. «synchrony», p. 7
  2. Coincidence: similar positions, full or lagged, p. 8
  3. Opposition: bi- or multi-polar arrangement, e.g. spatial splitting, p. 8
  4. Constancy: "movement patterns remain the same (...) for a particular duration", p. 8
  5. Convergence: synchronous or delayed, "movement to the same location". See «encounter», p.9
  6. Divergence, synchronous or delayed: movement away from the same location. See also «breakup», p. 9
  7. Attraction. See also: «pursuit», p. 10
  8. Repulsion. See also: «evasion», p. 10

4. SYMBOLS

4.1 Early SSMN Spatial Taxonomy and Symbolic representation research

Initial decisions about symbol design concerned the approach to symbolic representation. As the taxonomy was being developed a provisional set of symbols was defined based on ongoing comparative studies of 2-D and 3-D graphic representation of spatial motion. Additional pertinent authors were Trevor Wishart (1996) [24], Bijan Zelli (2001) [25], Larry Austin (2004) [26], Lasse Thoresen [27], Bertrand Merlier (2008) [28] and Vincent Verfaille (2003) [29]. An overall design concept was adopted with the primary criteria requiring clarity, legibility and rapid recognition through reliance on simple visual symbols such as cube, sphere, radar, perspective, arrows, colors, size, etc. (see figure 1).

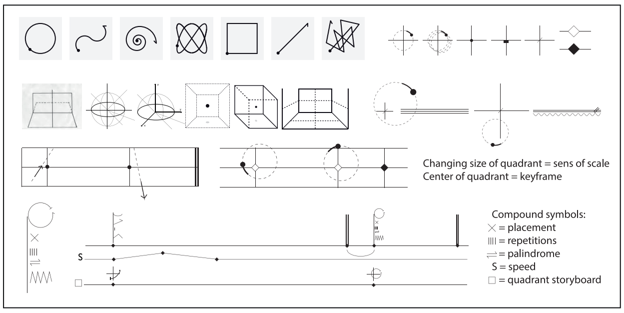

Figure 1. Example of early symbol design research.

This basic set was improved in subsequent design loops. The following major issues came up during the process:

- Defining "symbolic" as opposed to "descriptive" (i.e. icon versus image)
- Creating a grammar such as the creation of compound symbols (e.g. a circle with vibrato-type movement including acceleration) or determining a set of regrouped staves/tracks for which a common action is proposed)
- Determining parameters of SSMN symbols
- Establishing a timeline with key frames (e.g. a dedicated staff) allowing continuous activity of a symbol being reported on the timeline representation
- Pertinence of the use of a quadrant or grid to improve legibility (see figure 1, upper row, symbols 8-12)
- Creating tools for manuscript input to allow a degree of freedom for composers to deal with situations where the taxonomy would not provide the adequate tool for a specific idea (e.g. the utilization of a rubber-stamp for rapid manual input of composer's trajectory designs).

Several strategies of graphical possibilities had to be tested in view of integrating these symbols into the open source score editor MuseScore.

4.2 SSMN Symbol set

This process led to the actual symbol set consisting of the following categories:

- Physical performance space characteristics
- Initial physical placements of performers, microphones, loudspeakers and objects
- Position of sound sources (RS, PA)
- Trajectories / displacement of sound sources, microphones, loudspeakers and objects
- Operations
- Stop/End markers delimiting the time domain of symbols (see “Working with symbols” below)
- Inter-application communication resources (OSC, MIDI) for interaction with external programming environments

The last two are not explicitly contained in the taxonomy. They came up as a result of operational needs during the implementation stage.

Table 1 includes only symbols created according to the taxonomy. Some of them are already available within MuseScoreSSMN. Trajectories appear in two variations: single direction and back and forth.

Cube		Hemi-sphere	
Church		Other	
Performer		Perf_line	
Perf_arc		Music stand	
Audience		Micro-phone	
Loud-speaker		Swinging microph.	
Swinging loudsp.		Choreo-graphy	
Sound point RS		Sound point PA	
Group RS		Group PA	
Plane		Scale	
Straight		Polyline	
Poly_ closed		Circle	
Slinky		Spiral	
Bézier		Bézier_ spline	
Béziergon		Bernoulli	
Sinus		Triangle	
Square		Saw	
Random		Algo	

Table 1. Symbols designed according to the taxonomy

The symbols shown in Table 2 complement those referring directly to elements of the taxonomy. They specify further positions and movements of sources or address new elements and functionalities. The first two rows include additional types of movements of performers. The next two rows introduce stop markers for trajectories and modifiers as well as special markers for defining pauses within a trajectory without sound interruption. The next row presents symbols defining alternate movements of points and groups. The following two rows specify 3D positions of points and groups, the next one the position of planes. The symbols in the last row allow for the definition of inter-application communication and a dedicated SSMN staff respectively.

Perf_rotate		Perf_free	
Perf_to&from		Perf_other	
Trajectory _end		Modifier_end	
Pause_start		Pause_end	
Alternate_ point		Alternate_ group	
3D_point (RS)		3D_point (PA)	
3D_group (RS)		3D_group (PA)	
Root_plane back		Root_plane front	
Communica-tion OSC		SSMN Staff	

Table 2. Additional symbols

4.3 Working with symbols

Figure 2 below illustrates the basic workflow within MuseScoreSSMN: (A) selection of a symbol from the “SSMN Palette”; (B) placement in the score; (C) definition of parameters in the “Inspector window” corresponding to the symbol chosen; (D, E) display of the trajectory or trajectories designed by the user in the interactive “Radar window”. This window contains a top and a side view (E). Each circle corresponds to 10 spatial units to be scaled according to the real space.

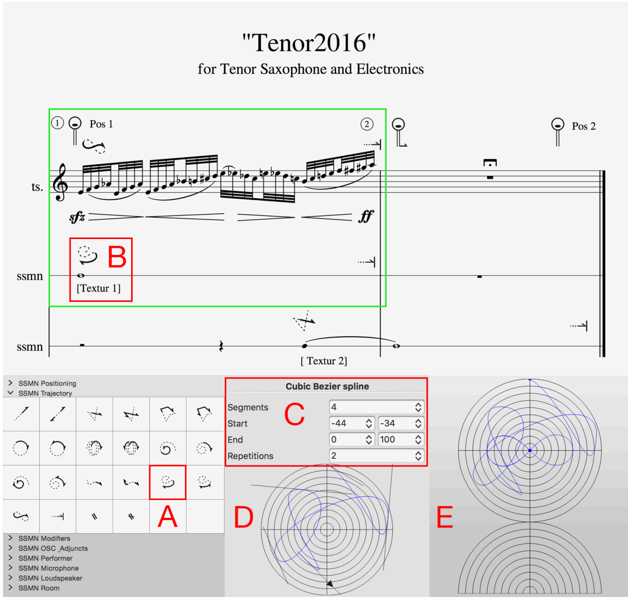

Figure 2. Workflow within MuseScoreSSMN.

In this example the phrase played by the tenor saxophone will be picked up by a microphone (projected audio) and spatialized according to the "Bernoulli" symbol (see Table 1) placed above the staff at the beginning of bar 1. The corresponding "Trajectory_end" symbol (see Table 2) at the end of the first bar marks the exact point in the timeline at which the trajectory ends, thus defining its effective duration. The initial position of the performer (root sound) is defined by the "Performer" symbol (see Table 1). After playing bar 1 the player is asked to move towards a new position defined by a similar symbol at the end of bar 2. The trajectory used is defined by the "Perf_line" symbol (see Table 2) at the beginning of bar 2.

Additionally, two dedicated SSMN staffs have been set to define the spatialization of pre-produced samples. The movement of the sample named "Textur 1" is defined by a "Bézier_spline" symbol (B, see also Table 1). The resulting trajectory is shown in the radar window (D). It contains 4 control points (marked with tangents) and will be repeated once. The corresponding parameters including start and end positions (x, y) are shown in the inspector window (C). The sample named "Textur 2" begins at the fourth beat of bar 1. It was defined as a polyline. Both samples have "Trajectory_end" symbols above the corresponding staff. An SSMN staff can be used independently of musical events and become a timeline for other kinds of information (e.g. choreography notation, film editing).

The green line indicates a selection including the saxophone staff and the upper SSMN staff. The radar window (E) shows the superposition of both trajectories. Here the ends of the trajectories are highlighted with a point. The position of the performer is not displayed in the Radar window since it is not relevant for rendering.

4.4 Current developments

A basic operative feature to be implemented in the near future is the possibility of saving movement patterns defined by descriptors and modifiers. Another issue is the question of symbol activity in the context of digital representation possibilities. On one hand, having a score in the digital domain allows for much greater latitude in providing continuous information through windowing, with or without animation. On the other hand it might be necessary to reduce the displayed information in the printed version of full scores and parts for reasons of clarity.

New possibilities appear when imagining interaction through integration of various software applications dedicated to facilitating artistic processes. A collaboration between the research teams of "inScore" and "Faust" at GRAME (Lyon) and SSMN has recently been undertaken with the expectation of creating tools to facilitate interaction on a local level and in web applications for visual display and audio rendering purposes. Other aspects being currently investigated are SpatDIF compatibility and the integration of SSMN Elements within the MusicXML protocol.

5. CONCLUSIONS

Results of the SSMN project have already been tested with composition students at the Zurich University of the Arts and presented at the Haute École de Musique of Geneva. This experience has revealed encouraging developments, such as increased awareness of spatialization possibilities within the composition process and augmented spatial listening acuity. The main intention of the project is to reflect on the ways we think of and work with spatiality in composition and to envision procedures that integrate spatiality from the very beginning. The software prototype is intended as a tool that facilitates the exploration of such procedures. Further tests and experiences should help to clarify if similar workflows can become practical and open enough to meet the necessities of different composers.

The taxonomy presented here reflects approaches to spatialization based mainly on geometrical and visual concepts such as lines, curves and planes. New organization paradigms can be envisioned by introducing time based dynamic movement patterns as observed in biological and social contexts. The persistent idea of sound as an object, closely related to visual and geometric concepts, could be challenged by an understanding of sound as a continuously changing field of energy, as the result of interacting information streams. Although the emergence of new notation paradigms will be supported by an evolving technology that already makes possible the integration of interactive interfaces in performance practice, it can be assumed that conceptual thinking in composition will remain the major source of aesthetic innovation of spatialization in electroacoustic music.

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