FROM SPATIALIZATION TO SPATIAL STRUCTURE: A SPATIAL GRAMMAR FOR ELECTROACOUSTIC COMPOSITION

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ABSTRACT

Spatialization has become a central dimension of electroacoustic music, yet compositional approaches often remain tied to specific rendering technologies such as Wave Field Synthesis, Ambisonics, or multichannel diffusion. This dependency raises a compositional challenge: how can spatial structures remain meaningful across different spatial audio systems? This paper proposes Spatial Grammar as a compositional framework that separates spatial structure from rendering technologies. Drawing on spectromorphological theory, spatial perception, and perceptual articulation, the framework organizes spatial processes across multiple levels—parametric, gestural, functional, and syntactic—through which spatial relationships contribute to musical form and perceptual organization. The approach is developed through the electroacoustic work Risonanze, originally composed in a Wave Field Synthesis environment, where spatial parameters directly influence sound generation and transformation. Its translation into an eight-channel configuration highlights the limitations of system-dependent spatial composition. To address this issue, the paper presents a compositional tool that translates spatial structures across rendering environments via intermediate data representations. More broadly, the study proposes a compositional paradigm in which spatial structure is decoupled from rendering, allowing space to function as an active and transferable dimension of musical organization.

1. INTRODUCTION

Spatialization has become a central dimension of electroacoustic music, expanding the traditional musical parameters of pitch, timbre, and time into the spatial domain. Over the past decades, numerous spatial audio technologies have been developed, including multichannel loudspeaker systems, Ambisonics, and Wave Field Synthesis. These technologies have significantly expanded the possibilities for spatial sound composition, enabling complex spatial trajectories, distributed sound fields, and dynamic spatial transformations. However, the expansion of spatial audio technologies also raises a broader compositional question about the role of space in musical organization. As Brümmer [1] discusses, a distinction must be made between spatialization, which operates at the level of rendering, and space as a compositional parameter, in which spatial relationships actively shape musical structure—a distinction further contextualized in Section 2 and developed in Section 3. The concept of Spatial Grammar proposed in this paper supports this perspective by providing a framework for organizing spatial structures within the compositional process independently of their rendering technology. The compositional approach developed in this research emerged during the composition of the electroacoustic work *Risonanze*. While working within the Wave Field Synthesis environment provided by WFS Collider, spatial parameters began to influence not only the distribution of sound in space but also the transformation of sonic material itself. In this context, spatial trajectories, spatial density, and spatial interaction between sound objects became closely intertwined with processes of sound generation and processing. The architecture of WFS Collider encourages this approach by allowing spatial behavior to be embedded within nested functional structures that combine sound synthesis, transformation, and spatial trajectories [2]. This perspective can be summarized as the transformation of sound through spatial parameters, in which spatial behavior operates as an active compositional driver [3]. At the same time, this close integration between compositional processes and a specific spatial audio environment also exposes a problem of portability. Spatial composition often remains closely tied to the rendering system used during the compositional process. Many works are conceived directly within a particular spatial audio environment, where the design of spatial structures is strongly influenced by the characteristics of the playback system. As a result, spatial structures may become difficult to translate when the work is performed in a different spatial configuration. This paper addresses this challenge by investigating how compositional spatial structures can retain their musical meaning when translated across heterogeneous rendering systems. Within this perspective, spatial processes are organized across multiple structural levels—parametric, gestural, functional, and syntactic—allowing spatial position, movement, and extent to operate as compositional elements capable of shaping musical form and perceptual organization. The present research therefore investigates the interplay between compositional spatial structures and spatial rendering technologies. This shift can be summarized as a transition from a model in which spatialization follows sound processing to one in which spatial parameters actively shape sound

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transformation. The difference between these approaches is illustrated in Fig. 1.

The electroacoustic work *Risonanze*, originally composed for Wave Field Synthesis using WFS Collider, serves as the case study through which this problem is examined. Its current eight-channel version represents an adaptation of the original spatial design, illustrating the challenges involved in translating compositional spatial structures between different spatial audio systems. To address this issue, the present research includes the development of a compositional tool aimed at facilitating the translation of spatial structures across rendering environments. In its current prototype stage, trajectory data exported from WFS Collider are converted into intermediate representations that can be interpreted in other production environments. The long-term objective is to support a compositional workflow in which spatial structures can be defined independently of their final rendering system, enabling greater flexibility in spatial music composition.

2. BACKGROUND: SPATIAL SOUND AND PERCEPTION

Research on spatial sound in electroacoustic music has developed along multiple intersecting lines, including technological approaches to spatial audio reproduction, perceptual studies of spatial hearing, and compositional frameworks addressing the musical role of space [4]. Spatial perception plays a crucial role in the organization of electroacoustic sound structures [5, 6]. From a technological perspective, several spatial audio reproduction systems have been developed in order to control the distribution and movement of sound within a listening environment. Among the most influential approaches are multichannel loudspeaker systems, Ambisonics, and Wave Field Synthesis [7]. These technologies have expanded the possibilities for spatial sound composition, enabling dynamic spatial trajectories, distributed sound fields, and immersive listening environments. Technological accounts of computer music have traditionally focused on spatialization as a set of techniques for sound diffusion, panning, reverberation, and reproduction [8]. However, the development of spatial audio technologies has not always been accompanied by a corresponding development of compositional frameworks capable of describing spatial structures in musical terms. Several authors have addressed the perceptual and morphological aspects of spatial sound in music. The spectromorphological theory developed by Denis Smalley introduced the concept of spatial motion and spatial distribution as perceptually significant attributes of sonic morphology [5]. Within this framework, spatial behavior participates in shaping the listener's perception of sonic events and musical processes [6]. Smalley's later reflections on space-form and spatiomorphology are particularly relevant to the present work, since they examine the role of space in the perceptual articulation of musical form. Research in spatial hearing and computer music has also contributed to understanding the perceptual organization of spatial sound. Studies by Gary Kendall have explored how listeners perceive spatial attributes such as localization, distance, and movement in multichannel environments [9]. These studies highlight the importance of spatial cues in structuring auditory perception [10]. Compositional perspectives on spatial sound have also been developed within electroacoustic music practice. For example, Pablo Di Liscia has proposed approaches to spatial articulation in electroacoustic composition, emphasizing the relationship between spatial organization and musical structure [11]. Similarly, theoretical reflections emerging from Latin American electroacoustic traditions have highlighted the role of perception in the organization of musical parameters, as discussed in the work of Francisco Kröpfl [12]. Despite these contributions, spatial composition often remains strongly influenced by the specific technologies used for spatial rendering. Many works are conceived within particular spatial audio environments, which may limit their adaptability to other playback systems. This situation suggests the need for compositional frameworks capable of describing spatial structures independently from specific spatial rendering technologies. The concept of Spatial Grammar proposed in this paper seeks to address this issue by providing a framework in which parametric spatial transformations can acquire structural relevance within the compositional process.

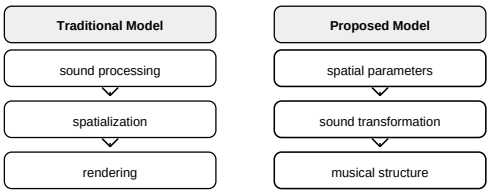


Figure 1. Comparison between traditional and proposed compositional models. In the traditional model, spatialization follows sound processing as a rendering stage; in the proposed model, spatial parameters actively shape sound transformation within the compositional process.

3. SPATIAL GRAMMAR

This framework aims to describe spatial processes as structural components of musical organization rather than as secondary parameters of sound reproduction. Building upon the distinction between spatialization and space as a compositional parameter introduced in the previous section [1], the present framework focuses on the role of spatial relationships within the compositional structure itself. Spatialization typically refers to rendering techniques that control the distribution or movement of sound within a playback system. Although such techniques can influence compositional practice, they primarily operate at the level of sound reproduction. By contrast, conceiving space as a compositional parameter implies that spatial relationships actively contribute to shaping musical form and perceptual organization.

Based on the theoretical approaches outlined in the previous section, the framework proposed here addresses the same domain from a different perspective [5, 6, 9,

10]. Rather than describing spatial phenomena primarily through their perceptual articulation, Spatial Grammar organizes relationships between structural levels within the spatial domain and formalizes how transformations at the parametric level may give rise to gestural, functional, and syntactic organization. For example, a parametric transformation, whether of a sound object (position, motion, width, diffusion) or of the field (extension, enclosure, envelopment), becomes structurally relevant when it modifies the organization of the sound-space field, producing changes in integration or externalization, unity or plurality, expansion or contraction of the field, continuity or discontinuity, or the emergence of perceptually salient spatial gestures.

Many existing frameworks implicitly describe a progression in which spatial attributes are first considered at a parametric level and subsequently organized into higher-level functional and syntactic structures from which perceptual phenomena such as gesture emerge. The present approach departs from this perspective by assigning gesture an active mediating role within the compositional process. Rather than being understood solely as the outcome of structural organization, spatial gestures can themselves influence the formation of functional and syntactic organization.

Within this perspective, spatial behavior can interact directly with processes of sound generation and transformation. In some compositional environments, spatial parameters influence the internal behavior of sound processes, creating situations in which motion, width, diffusion, and spatial relationships within the sound-space field become closely intertwined with the evolution of the sonic material [2, 3].

From this perspective, the central question is not whether a spatial parameter is present but when a parametric transformation acquires structural relevance within the musical discourse.

The Spatial Grammar framework organizes spatial processes across multiple structural levels. Although these levels may be described from a bottom-up perspective, they are analytical categories rather than perceptual stages, and they operate as an interdependent system rather than as a strict hierarchy. Parametric spatial transformations are therefore conceived according to the structural organizations they are intended to produce. Within this framework, gestural phenomena mediate between parametric conditions and higher-level functional and syntactic organization. Rather than prescribing compositional procedures, the four levels provide criteria for evaluating how spatial operations acquire structural relevance. A spatial decision becomes compositionally relevant when a parametric transformation affects gestural salience, functional or syntactic organization within the sound-space field (Fig. 2).

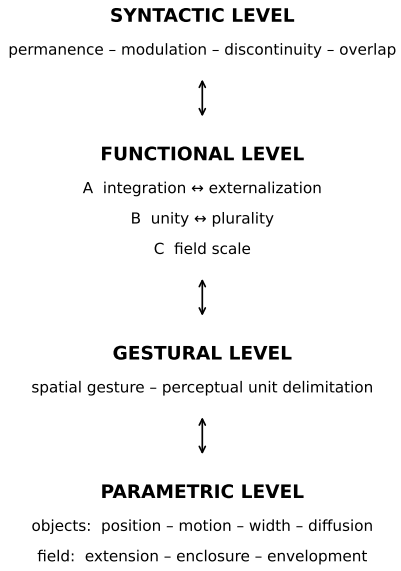


Figure 2. Spatial Grammar framework. Spatial processes are organized across parametric, gestural, functional, and syntactic levels. The syntactic level is placed at the top for expository convenience.

3.1 Parametric Level

At the most basic level, spatial behavior can be described through a set of spatial cues, some referring to sound objects and others to the field in which they are heard. Object cues include position (direction and distance combined), motion (change of position), width (the extent of the field a sound image occupies), and diffusion (the degree of definition of its boundaries). Field cues describe the space as a whole: extension (its perceived size), enclosure (whether the listener is inside it or facing it), and envelopment (sound arriving from all around). At this level, space is conceived as a continuous spatial field within which sound objects can occupy positions or follow trajectories. This perspective contrasts with approaches based on discrete loudspeaker positions and becomes particularly relevant in spatial audio environments such as Wave Field Synthesis [7]. Spatial trajectories can, therefore, be understood as processes unfolding within a spatial field rather than simply transitions between loudspeakers.

3.2 Gestural Level

At the gestural level, spatial variations are grouped into perceptual units. Spatial gestures emerge when spatial movement or transformation produces a perceptually significant event within the musical discourse, delimited in time on both sides. A spatial gesture may consist of a trajectory, an expansion or contraction of the field, or a sudden reorientation of spatial relationships. These events often operate as perceptual accents that articulate the evolution of the musical material. Following the work of Kröpfl [12], musical discourse can be understood as a process in which perceptual accents contribute to structuring the listener's experience. In this framework, spatial gestures are not considered as the final outcome of structural organization, but as active elements that can influence the formation of higher-level relationships. Gesture is thus both emergent and generative.

3.3 Functional Level

At the functional level, spatial processes describe relationships between sound and the spatial field, often mediated by gestural phenomena. Three domains can be identified. The first, Spatial Fusion, concerns the degree of sound–space integration, ranging from integration to externalization. The second, Spatial Field Organization, concerns the articulation of the spatial field itself, which may be perceived either as a unified configuration or as a plural spatial structure. The third, Field Scale, concerns the expansion or contraction of the field itself. These functional processes influence the perceptual organization of the musical texture and can interact with other musical parameters such as dynamics, timbre, or spectral density, in line with perceptual models of auditory organization [5]. Foreground–background relationships, discussed in the spatial audio literature as perceptual attributes, are not treated here as parametric primitives: distance is a parametric cue, whereas the relation it helps to establish is functional, since it concerns the role a configuration assumes with respect to the others. Within the Spatial Grammar, such relationships are interpreted as consequences of functional organization, resulting from different degrees of integration and externalization within the sound-space field.

3.4 Syntactic Level

The syntactic level concerns the organization of spatial processes across time. Spatial trajectories, spatial transformations, and changes in spatial distribution may form patterns that contribute to the articulation of musical form. Spatial syntax may involve processes such as permanence, modulation, discontinuity, or overlap (temporal superposition) of spatial configurations. These processes may operate at different temporal scales, from short gestural events to large-scale spatial transformations across the entire work. Within this perspective, spatial structures emerge from the interaction of parametric conditions, gestural articulation, and functional organization, contributing to the articulation of sections, transitions, and formal processes.

3.5 Interaction Between Levels

The four levels described above should not be understood as isolated layers nor as a strictly hierarchical system, but rather as interdependent components within a compositional field. While a bottom-up perspective can be identified—from parametric conditions to gestural articulation, functional and syntactic organization—these levels continuously interact and influence one another. The electroacoustic work *Risonanze* provides an early example of this approach. During its composition, spatial parameters and sound processes were designed within a unified compositional environment, allowing spatial parameters and sound processes to evolve within a unified compositional environment. Spatial trajectories, understood as one of the categories operating at the parametric level, illustrate how transformations occurring at this level may influence the organization of the sound-space field across gestural, functional, and syntactic levels. Spatial behavior therefore did not merely function as a means of spatial rendering, but actively contributed to shaping both the evolution of sonic material and the articulation of spatial structures. This interaction between spatial parameters and sonic processes forms the conceptual foundation of the Spatial Grammar framework and motivates the development of compositional tools capable of supporting spatial structures independently from specific spatial rendering systems. This issue becomes particularly evident when spatial structures defined within a compositional framework are translated into specific rendering environments.

4. SPATIAL RENDERING AND TRANSLATION OF SPATIAL STRUCTURES

One of the central challenges in spatial music composition concerns the relationship between compositional spatial structures and the technologies used to render them. Spatial structures emerge from the interaction of spatial parameters with higher-level gestural, functional, and syntactic organization. At the parametric level, these include the position, motion, width, and diffusion of sound objects and the extension, enclosure, and envelopment of the field. Through their interaction, such parameters may generate functional organization such as sound–space integration, the articulation of unified and plural spatial fields, or the expansion and contraction of the field. Among the parametric categories, spatial trajectories are the most widely implemented forms of spatial representation in contemporary spatial audio systems, but they constitute only one possible realization of broader compositional spatial structures. This dependency becomes particularly evident when a work composed for one spatial reproduction system needs to be performed within another configuration. Spatial structures designed for one rendering method may not translate directly into another, since the parameters through which they are represented, as well as coordinate systems and loudspeaker distributions, differ significantly across technologies such as multichannel systems, Ambisonics, and Wave Field Synthesis. The electroacoustic work *Risonanze* illustrates this situation through a trajectory-based compositional approach. The piece was originally composed within a Wave Field Synthesis environment using the software WFS Collider. In this particular case, spatial trajectories constitute the principal representation through which spatial structures are articulated. Spatial behavior is therefore defined through continuous trajectories within a spatial field rather than through discrete loudspeaker positions. Wave Field Synthesis enables the reconstruction of sound fields across extended listening areas [7], allowing spatial motion to be conceived as continuous movement in space. Within WFS Collider, spatial trajectories are stored using the (`.wfspath`) format. These trajectory descriptions are closely integrated with the internal architecture of the environment, where sound synthesis, signal processing, and spatial behavior are combined within nested functional structures. This integration encourages a compositional approach in which spatial parameters interact directly with sound generation and transformation processes. When

WFS Collider exports spatial trajectories for multichannel reproduction, the rendering no longer relies on Wave Field Synthesis. Instead, spatial positioning is translated into a loudspeaker-based panning method using Vector Base Amplitude Panning (VBAP) [13]. In this configuration, virtual source positions are approximated through amplitude distribution between loudspeakers rather than through the physical reconstruction of wavefronts. As a consequence, the spatial rendering of the work differs from the spatial conditions present during the compositional process. While Wave Field Synthesis enables the reconstruction of continuous sound fields, VBAP-based rendering represents spatial positions as amplitude relationships between discrete loudspeakers. This difference highlights a broader issue: compositional spatial structures conceived within one spatial reproduction paradigm may undergo significant transformation when rendered through another. When spatial structures are translated between rendering paradigms, the exact realization of spatial parameters may change according to the characteristics of the target system, and consequently, aspects such as spatial continuity, localization, rendering precision, or the geometric configuration of parametric relationships cannot generally be preserved. From the perspective of the Spatial Grammar, however, the objective is not to preserve the exact realization at the parametric level, but the structural organizations that these parameters generate across the higher levels of the grammar. Parametric transformations acquire compositional relevance through the gestural, functional, and syntactic organization they produce. In the opening section of *Risonanze*, for example, the progressive divergence between the trajectories of the resonances and that of the primary sound object gradually reorganizes the sound-space field by transforming an initially integrated and unified spatial configuration into a more externalized and plural one. This functional reorganization corresponds to that of the original WFS version, even though the exact trajectories and their rendering differ in the eight-channel adaptation. Although the exact trajectories cannot be reproduced identically within a different rendering paradigm, this functional organization may remain compositionally meaningful when the precise rendering of the parametric relationships changes. This example shows that the structural relevance of a spatial process does not depend on the literal preservation of its parametric configuration, but on the organization it produces within the musical discourse. From the perspective of the Spatial Grammar, spatial parameters can therefore be understood as an abstraction layer capable of preserving compositional structures across different rendering methods. The current eight-channel version illustrates this situation. Rather than constituting a direct translation of the original compositional spatial structures, it represents an intermediate rendering in which the functional organizations generated during the compositional process are preserved, while the rendering of spatial parameters necessarily changes according to the target rendering system. Trajectory data exported from WFS Collider (`.wfspath`) are converted into an intermediate CSV representation. These data are subsequently interpreted through Lua scripts in Reaper, allowing the reconstruction and adaptation of spatial structures within different rendering environments. The workflow is currently conceived as a compositional support tool rather than an automatic rendering conversion. At this stage, it is evaluated primarily through compositional use, by assessing whether the translated structures preserve their functional role within the musical form rather than by measuring perceptual equivalence between rendering systems. This conversion workflow allows spatial trajectories to be reconstructed in environments such as Reaper, where they can be used to control spatial parameters of multichannel audio tracks. Although the current process requires several intermediate steps, the long-term objective is to integrate this translation mechanism into a Max-based compositional tool. Such a tool would enable compositional spatial structures, represented in this case through trajectories, to be translated into multiple rendering formats. By separating the representation of spatial structures from the playback system, the compositional process becomes more flexible and adaptable to different spatial audio environments. This approach shifts the focus from preserving a specific spatial rendering to preserving the underlying compositional spatial structure. By introducing an intermediate representation of spatial trajectories, the proposed workflow provides a practical implementation of this abstraction layer across different rendering systems. In this sense, spatial composition can be decoupled from the constraints of specific spatial audio technologies, allowing spatial structures to be translated, adapted, and reinterpreted across heterogeneous environments. This perspective aligns with the concept of Spatial Grammar proposed in this paper, where spatial relationships are conceived as structural elements of musical organization rather than as by-products of sound diffusion. More broadly, this approach suggests a compositional paradigm in which space operates as an active and transferable dimension of musical structure, opening the possibility for new tools and methods that integrate spatial design directly within the compositional process.

The translation process is illustrated in Fig. 3.

5. CONCLUSIONS

The research presented in this paper investigates the role of space as a structural parameter in electroacoustic composition. Although contemporary spatial audio technologies provide advanced techniques for sound reproduction, compositional approaches often remain closely tied to specific rendering systems, limiting the portability of spatial works across different environments. The concept of Spatial Grammar proposed in this study addresses this issue by describing spatial structures independently from their technological realization. By organizing spatial behavior across parametric, gestural, functional, and syntactic levels, the framework enables spatial relationships to operate as structural components that shape both musical form and perceptual organization. The electroacoustic work *Risonanze* illustrates how spatial parameters can interact directly with processes of sound generation and transformation. Originally conceived within a Wave Field Synthe-

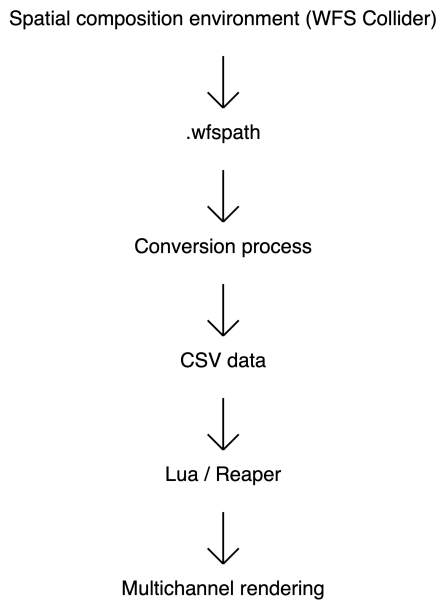


Figure 3. Workflow for translating spatial trajectories between spatial audio environments. Spatial data generated in WFS Collider (.wfspath) are converted into intermediate representations (CSV) and reconstructed in a digital audio workstation environment through scripting, enabling multichannel rendering.

sis environment, the work demonstrates how spatial trajectories can influence the evolution of sonic material rather than merely determining its spatial placement. The translation of this work into an eight-channel configuration further highlights the challenges involved in transferring spatial compositions between different rendering systems. In response, the development of a compositional tool for the translation of spatial trajectories introduces an intermediate representation that facilitates the adaptation of spatial structures across heterogeneous environments. This research suggests a compositional paradigm in which spatial structure is decoupled from spatial rendering. Within this perspective, space emerges as an active and transferable dimension of musical organization, capable of supporting new compositional strategies and tools that integrate spatial design directly into the creative process. This shift opens new possibilities for the development of integrated compositional environments in which spatial thinking becomes intrinsic to musical creation rather than dependent on its technological implementation.

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