

ERGODIC AND EMERGENT QUALITIES OF REAL-TIME SCORES. ANNA & MARIE AND GAMIFIED AUDIOVISUAL COMPOSITIONS

Andreas Pirchner

University of Music and Performing Arts Graz
andreas.pirchner@kug.ac.at

ABSTRACT

This paper describes the functionality and aesthetic implications of the real-time score-system developed for the composition *Anna & Marie* by Marko Ciciliani. It originates from the artistic research project GAPPP and was first performed at Donaueschinger Musiktage 2019. By referring to examples of historic tendencies towards non-linear scores, the terms ergodicity and emergence are introduced to the understanding of the score properties of the real-time virtual performance space. This first part is then exemplified by describing the ergodic score of *Anna & Marie*. A particularity of this work is that two violinists navigate avatars in two virtual 3D environments by their manner of playing. The environment offers distinct audiovisual situations distributed in the virtual space and is identified as a spatial score. The musicians' musical effort of spatially traversing the virtual performance space consequently allows the audiovisual gestalt of the performance to emerge. The entanglement of spatial score and symbolic score, generated and presented on tablets, and mediated by the performers, is shown to be a characteristic of the composition. It is investigated, how the emerging performances question a notion of ergodicity where a prior text is followed by a technology reproducing it. In conclusion, the group of categories of real-time scores is extended by ergodic emergent scores.

1. INTRODUCTION

1.1 Technology of Real-Time Scores

The progress in and increased availability of computer technology have allowed artists and engineers to realize a multitude of setups for generating and rendering scores for performers in real-time¹, thus expanding the notion of what Umberto Eco [2] described using the term "open work". Artworks of GAPPP fall into the category of open works. Common characteristics are that they are ergodic,

that they involve one or more human performers as well as nonhuman agents, and that they find individual ways of generating and communicating scores and instructions to the performers. They also adopt a variety of media technological setups, some of which I will describe.

Real-time technologies: Recent developments in frameworks for network and server technologies like node.js [3] have made it possible to build lightweight and dedicated network services for apps and browser apps. Simultaneously, the rise of JavaScript promoted the use of the language for front and back end equally, making browsers a preferable target for application development. Frameworks like Electron [4] provide the advantage of development independently from mobile and desktop operating systems in a single JavaScript, HTML and CSS environment. Recently, some of these technological developments have been adopted for real-time generation of scores in browser environments [5, 6].

Spatial technologies: At the same time, the advancements of open-source real-time 3D development platforms like Unity [7] allow composers to realize their audiovisual ideas in 3D as well as to explore new forms of the open work by adopting strategies from digital games. These artistic explorations have encouraged new and nontraditional ways of communicating score elements and instructions to the performers. The interplay of entities that serve the function of a score in the composition *Anna & Marie* draws on both the spatial and real-time technology strands of these developments. The symbolic score² generated in real-time is tightly interwoven with the characteristics of the virtual performance space that equally function as a score.

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¹ For an overview of recent works see for example [1].

² The term "symbolic score" is used in a semiotic sense and refers to scores communicating playing instructions to performers by using visual symbolic systems. These systems can include traditional musical notation symbols or individual artistic inventions of symbolic scores, often labeled as experimental or avant-garde. The term will later be used to distinguish these symbolic representations from the notion of spatial scores.

As some of the underlying concepts can be traced back to notions advocated at the GAPP project, a brief background of the project will be provided along with an argument for possibilities for describing characteristics of scores for a gamified musical work.

1.2 Gamified Audiovisual Performances

GAPP (*Gamified Audiovisual Performance and Performance Practice*) is an artistic research project currently carried out at the Institute for Electronic Music and Acoustics (IEM) at the University for Music and Performing Art in Graz/Austria. One of the goals of GAPP is to explore the potential of digital games to offer models for audiovisual compositions and performances. The research is carried out from three points of view: audience perception is researched and informed by musicology, digital games theory and methods of social sciences (Andreas Pirchner); contemporary electro-acoustic audiovisual composition (Marko Ciciliani); and performance practice (Barbara Lüneburg). In an iterative process, the researched artworks are commissioned and composed for the project. Composers decide which elements of digital games they want to adopt for their work. Common characteristics demonstrated are that the artworks are *ergodic* [8], that they involve one or more human performers in addition to virtual non-human actors, and that they find individual ways of generating and communicating scores and instructions to the performers by adopting a variety of media technological setups.

2. ERGODIC AND EMERGENT SCORES

2.1 From Linearity to Ergodic Spaces

The score as an ergodic text: The notion of a space of possibilities, in which the actual game performance unfolds³ is common in digital game theory [9]. By the middle of the 20th century, the idea of making decisions and possibilities a part of compositions had gained some popularity among the avant-garde. Composers such as Henri Pousseur (*Scambi*, 1957), Earle Brown (*Twenty-five Pages*, 1953), and Karlheinz Stockhausen (*Klavierstück XI*, 1957) delved into the potentials offered by an open form. Pousseur was cited by Eco on the composition *Scambi* (1957): “Scambi is not so much a musical composition as a field of possibilities, an explicit invitation to exercise choice” [2].

As scores explored different symbolic notations, composers invented new ways of giving playing instructions. They asked performers to make their own decisions on how to proceed through modules of the composition. The performers were invited to shape the form of the composition’s performance both actively and in situ. However, these scores usually were still physically fixed by the composer prior to performances; their medium was mostly ink on paper, and the scores themselves were not generated or altered in real-time. Nevertheless, these characteristics

foreshadow what later would be theorized by Espen Aarseth [8] through adopting the term “ergodic” to literature and art in the 1990s. The rise of hypertext and the network metaphor further popularized this term, and it became an important concept in early computer game studies:

During the cybertextual process, the user will have effected a semiotic sequence, and this selective movement is a work of physical construction that the various concepts of ‘reading’ do not account for. This phenomenon I call ergodic, using a term appropriated from physics that derives from the Greek words ergon and hodos, meaning ‘work’ and ‘path’. In ergodic literature, nontrivial effort is required to allow the reader to traverse the text. [8]

Following Aarseth’s argument that a cybertextual process is not equal to reading a text, the process of navigating through a score of musical modules or even a score generated in real-time likewise is not equal to reading a score from a sheet of paper and demands that the performers make a non-trivial effort.

Pierre Boulez describes the initiative he requests from musicians performing his open-form composition *Constellation-Miroir* (1958/1959) as follows: “Certain directions are obligatory, others optional, but *everything* must be played. In some ways, this *Constellation* is like the map of an unknown city [...]. The itinerary is left to the interpreter’s initiative; he must direct himself through a tight network of routes” [10]. Boulez asks performers to navigate through the routes mapped out by the composition. Based on this brief historical outline, we will refer to specific scores that are rooted in traditions of Western avant-garde music as ergodic.

The score as an ergodic space: The score as an ergodic space: Both the notion of a “field” of possibilities (Pousseur) and the metaphor of the “map” (Boulez) suggest that the ergodic process expands the one-dimensional linearity of text and notation towards a two-dimensional space. While it was not uncommon for composers throughout the centuries to explore spatiality as a sonic parameter, the orientation towards fields and maps in playing instructions as a notational and conceptional tool marks a significant departure from traditional scores. In contemporary music, one-dimensionality is seen to be overcome not only through scores generated in real time (as described in [5]), but also through three-dimensional space and its augmentation towards virtual performance spaces. Referring to Tom Johnson’s composition *Nine Bells* (1979), Marko Ciciliani [12] characterizes the performance space not only as a parameter for composition but also as a mode of the score. He further demonstrates that the understanding of space as score applies not only to physical space, but also to virtual spaces. The distribution of sound sources in space can shape a composition’s time factor, depending on how performers traverse the composed spatial environment. With performers navigating a virtual open-world

³ We assume that a space of possibilities defines a class of all possible manifestations of a system. By making decisions, performers move through this space.

environment, there is no determined point in time at which sounds will occur. However, the performers are not without direction or constraint. The design of the topology, for instance, promotes certain spatial connections. Accordingly, some sounds are more likely to be played than others, because their occurrence is facilitated while others are more difficult to achieve. Ciciliani concludes that “each decision concerning the design of a 3D environment, such as the inclusion of obstacles and passages, will have indirect or direct musical consequences,” and consequently the virtual space takes on the role of a score. The full argument can be found in Ciciliani’s chapter “Virtual 3D Environments as Composition and Performance Spaces.” [12].

Softwares such as Unity even allows artists to manipulate and alter the virtual performance space through code at any time, and static physical rules do not necessarily apply. A striking example of this is Christof Ressi’s *Terrain Study*, which is discussed in detail in the chapter “Visiting the Virtual” (Lüneburg). These options offered to the artists lead the arbitrary space generated in real time to be regarded as a spatial score that is equally generated in real time. The virtual performance space’s openness to the arbitrary manipulation of its basic rulesets by code differs significantly from the way the physical performance space can be composed. These contemporary artistic practices continue the described historical concepts of the field of possibilities, open works, and corresponding techniques. However, they differ from earlier tradition in that the virtual spatial score is also part of the performance space; it is visible to the audience and becomes an integral part of the aesthetic experience of the composition.

Recent technology has made it feasible not only to compose score modules, but also to realize truly generative scores in a bottom-up process alongside the performance. The following section describes some fundamental characteristics of the resulting art and scores.

2.2 Emergence as a Characteristic of Scores

The term ‘emergence’ allows us to examine another specific characteristic of certain scores in ludified audiovisual performances. This term stems from philosophy and physics and describes a particular characteristic of complex systems. However, this text does not aim to contribute to the vibrant discourse in the philosophical field of emergentism, which pursues other epistemological and ontological goals. Instead, our argument builds on an understanding of emergence found in scientific fields such as biology and computer science. Here, the term is used to describe the effects of complex systems, distinguishing ‘emergent’ from ‘resulting’ effects. Resulting effects can be reduced to the sum of their individual causes, whereas emergent effects are characterized by the fact that neither can they be fully explained causally, nor are their expected system properties entirely predictable. For example, emergence was used in the theory of evolution to describe the problem that ‘higher’ properties of complex organisms cannot be fully explained by the interaction of the system properties and therefore differ by being novel.

Structures characterized as emergent can be based on simple rule systems. While swarm behavior, the formation

of dunes, and the shape of snowflakes illustrate emergent structures occurring in nature, a classic example of such systems in the computational field is James Conway’s *Game of Life* [13] (see figure 1). The original version of *Game of Life* (GoL) proposed by Conway in essence is deterministic. However, further developments introduced elements of chance, meaning that GoL no longer could be fully causally explained [14]. The notion of emergence here refers to the fact that unexpected and unforeseeable *gestalts* arise from the system of basic rules. The original version already was deterministic only in a mathematical sense, as the class of virtual objects that emerged, resulting in a rich taxonomy (with objects labeled “Pulsar,” “Beacon,” “Glider,” “Heavy-weight spaceship,” etc.), was certainly not predictable based on the underlying rules.

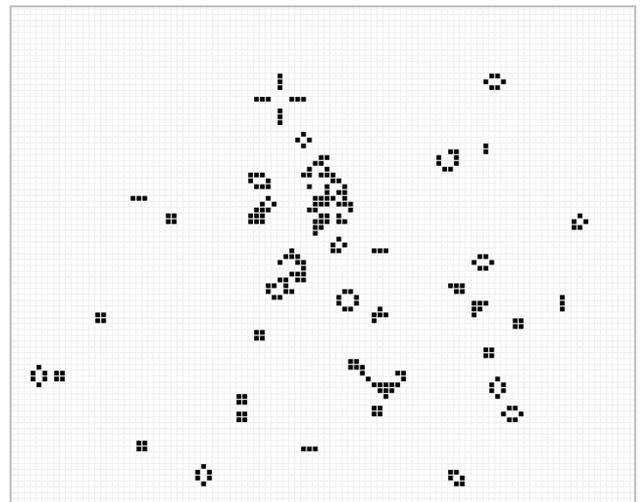


Figure 1. The visual structures of *Game of Life* are an example for a system where structures emerge from a basic set of rules (Screenshot of a JavaScript implementation, github.com/pmav/game-of-life).

Translated to the situation of ergodic scores, the notion of emergence helps us to understand a bottom-up process where sets of basic rules constitute the space of possibility offered to the performer. Through their activity, performers traversing this space mediate which manifestations of the composition emerge. While in *Game of Life* mathematical rulesets allow unforeseen visual artifacts to emerge, real-time symbolic musical scores appear to invert the direction of emergence. In these scores, visual symbols define an abstract set of rules that, as it stimulates the performer’s activity, provides the fertile ground for the emergence of the musical performance.

Earle Brown’s score for *December 1952* (see figure 2) exemplifies this notion. Brown asks the performers to follow a particular “path” as if in a two-dimensional open world. Of course, the flatland of the score itself does not offer sounding entities or sonic agents of the kind that contemporary composers might include.

In Christof Ressi’s composition *Game Over* (2018) [15], however, the two-dimensional performance space is inhabited by sonic agents (see figure 3). An accelerometer augments the performer’s clarinet, which functions as an interface, meaning that the performer is able to navigate

the virtual performance space by moving the instrument. By exploring different parts of the 2D map and by interacting sonically with the virtual sonic agents of the virtual performance space, the performer contributes particularly actively to the way that the audiovisual performance emerges from the interplay of virtual performance space and virtual sonic agents.

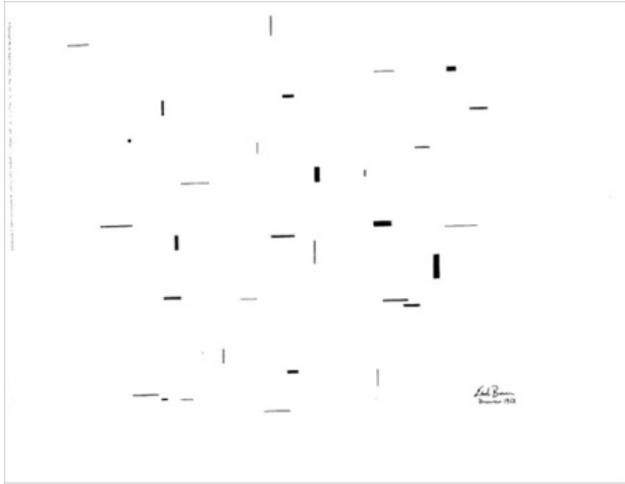


Figure 2. Earle Brown, December 1952. Earle Brown Collection, Paul Sacher Foundation, Basel. © by Associated Music Publishers, New York, 1961

The notion of the score as an ergodic space gives rise to new explanations of how performances emerge in contemporary art. In *Kilgore* (Ciciliani, 2017/18) [16], the three-dimensional virtual performance spaces offer a multitude of ways to traverse space and interact with sonic agents. The performers' activity in these spaces allows the gestalt of the actual performance to emerge from the composed spatial, sonic, and agential properties.



Figure 3. Christof Ressi Game Over (2018). © ndbewegtbild

The notion of this virtual spatial score explored by the performers thus differs significantly from the understanding of expanding one- or two-dimensional symbolic scores to three-dimensional score (as they are described for example in [17]). The interaction of the performers with the ruleset of the spatial score and thereby with sonic agents and the virtual world itself allows the musical work to emerge. In

this way, spatiality, activity, and perceivable performance thereby become inseparably entangled.

2.3 Scored Reality – Reality as Score

Aarseth laid out a rich taxonomy for ergodic literature (including 2-D examples) which in turn computer game theory developed strongly towards technology. Here, the concept of ergodic cybertext (as explained before in 2.1) implicitly assumes three main components. First, there has to be a specific “text”, or more generally, a space of possibilities that is open for reproduction and traversing. Second, there are players that traverse the text and explore the offered space of possibilities. And lastly, there has to be a technology capable of producing different manifestations according to the player's actions.



Figure 4. Barbara Lüneburg and Marko Ciciliani performing *Kilgore* (Marko Ciciliani, 2017/18) at Ars Electronica, Linz, 2018. © Andreas Pirchner

The reference to historical predecessors helped to find categories for the function of scores and virtual performance spaces used in ludified compositions. Their ergodic characteristics appear as twofold. On the one hand, performers can decide how to navigate through a score as a symbolic representation resembling a text like a field or a map. The score can be static, like in *December 1952* by Earle Brown, or real-time generated (as recently in [6]). On the other hand, the performance space itself, like in *Nine Bells* by Tom Johnson, may act as a score with performers traversing it and letting the composition emerge by their activity. Similarly, in several GAPP compositions performers traverse virtual three-dimensional (audiovisual) performance spaces or encounter entanglements of physical and virtual spaces as for instance in *Terrain Study* by Christof Ressi. These special ergodic situations particularly support emergent qualities as a bottom-up process. Mediated by technology, the process is more fundamental for how the performance emerges than in the described rather modular historical predecessors. It promotes a close entanglement of ruleset (text), performance spaces (space of possibility) and performer (reader). The entanglement of elements of the performance space and non-human agents results in what for the present paper I want to call an “ergodic and emerging score”.

3. THE COMPOSITION ANNA&MARIE

The following sections will briefly describe the composition *Anna & Marie* by Marko Ciciliani, based on the theoretical deliberations on emergence in open scores provided earlier and focusing on the aspects of the composition that are most relevant to the ergodic and emergent qualities of its real-time score system. A technical description of the different features of its score system and a subsequent analysis of its function and implications is provided.

*Anna&Marie*⁴ was composed by Marko Ciciliani as part of the GAPPP project and was first performed at Donaueschinger Musiktage 2019 by performers Barbara Lüneburg and Susanne Scholz.

Narrative: The narrative elements of the composition unfold around the historical figures of two wax sculptors, Marie Marguerite Bihéron and Anna Morandi. Both were pioneer anatomists of the eighteenth century. The storyline speculates about a fictional meeting between both women and how it could have taken place. The composition asks the performers navigating inside this story to make decisions at specific junction points. These decisions affect how the narrative unfolds. Therefore, the narrative and the performance are ergodic, and the composition can be regarded as an example of an open work.

Performance spaces: The two performers, on Baroque violin and E-violin, traverse the virtual performance space in first-person view according to how they play their instruments. The three-dimensional environment was developed in Unity, and the individual view of each performer is projected on a screen. The virtual performance space holds separate topologies for each performer. While the performers move through the virtual space, their position in the physical performance space remains static.

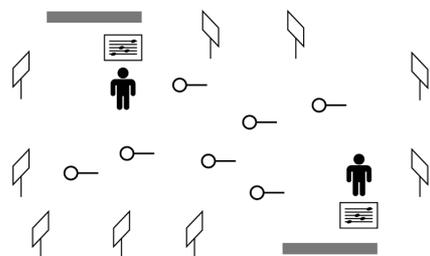


Figure 5. Elements of the physical performance space
 🧑 Performers
 📄 Symbolic real-time score
 🖥️ Screens displaying virtual performance space
 🎧 Audiovisual Augmented Reality Displays
 🎧 Headphones for the audience

The audience sits on cushions distributed across the room. Wireless headphones are available to the audience that provide the spoken text narration of the composition. The setup includes panels that show additional images related to the topic of the narration. The audience is invited to use

provided tablet devices to explore audiovisual Augmented Reality features of the panels (see Figure 5).

The composition comprises different layers of spatiality: (1) The physical performance space with the performers in fixed positions. (2) The virtual space, where the performers move by the way they improvise on their instruments. (3) Augmented reality panels that allow the audience to explore additional audiovisual elements individually. (4) Headphones lying in the room, allowing the audience to listen to the narrative parts of the performance individually.

Technological setup: The sound of both violins is analyzed in real-time by a computer program and fed into the performance system where synthetic sounds are generated in SuperCollider [18]. SuperCollider communicates with the Unity engine that generates the three-dimensional virtual performance spaces via Open Sound Control (OSC). SuperCollider also sends OSC messages to the dedicated score system generating symbols and playing instructions for each performer and rendering them on tablet displays.

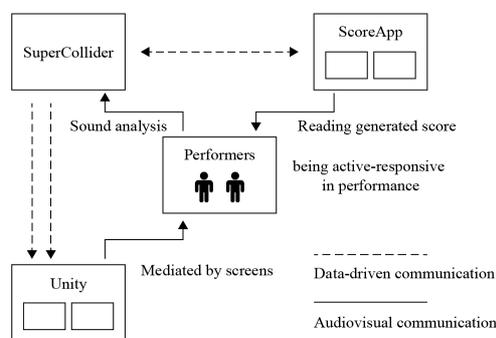


Figure 7. Basic technical setup of *Anna&Marie*.

On the one hand, *Anna & Marie* offers the performers a space of possibility to explore in a 3D environment. On the other hand, the performers' actions and decisions in the virtual space form the basis for generating and rendering the real-time score presented to them on tablet screens. The performers receive instructions on their manner of playing, dynamics, pitch sets, and how to relate to one another while playing. Within the confines of these instructions, they still have to make many individual choices on how to shape their parts in musical terms.

Navigating the spatial score: The performers traverse the spatial score/virtual performance space by playing their instruments (their sound is analyzed in real time and fed into the described performance system). Single long notes initiate turning points. If the notes following the long initial note are at a higher pitch than this note, this leads to a turn to the right, while notes below the initial note's pitch cause a turn to the left. When the players reach so-called junction points, they decide whether they walk past by it on its left or right side. This turn in the virtual space also marks a turn in the narrative and affects the way the relationship between the two main characters unfolds. The

⁴ For further information see the website of the festival: <https://www.swr.de/swrclassic/donaueschinger-musiktage/Donaueschinger-Musiktage-2019-Konzertante-Installation,veranstaltung-klangkunst-marko-ciciliani-19-10-2019-18-uhr-100.html>



Figure 6. Left side: Performance situation in the library at Donaueschinger Musiktage 2019. Right side: Projection of the virtual performance space, with the symbolic real-time score in the front.

decision also affects the way the symbolic score and playing instructions are rendered on the tablets for the performers. The symbolic score is therefore dynamic; the characteristics of the spatial score and the behavior of the performers in it also affect the way in which the symbolic score is rendered. The following section provides a more detailed description of the manner in which this part of the composition's score is designed.

4. THE SYMBOLIC SCORE SYSTEM

The following part of the text describes the functionality of the score system in detail. Those readers less interested in technical aspects are encouraged to continue to part 5. In an attempt to keep the code sections short when possible, the text references the project repository on GitHub: github.com/asa-nerd/Anna-und-Marie.

4.1 Basic Design of the Score System

Based on previous experiences, due to the increasing role of JavaScript in network systems, and for greater flexibility, it was decided to develop the scoring system to run in web-browsers.

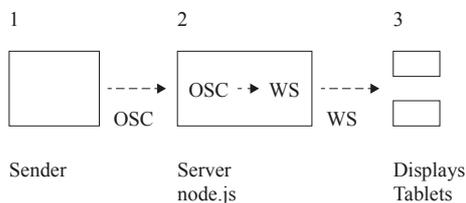


Figure 8. Schematic display of the developed symbolic scoring system.

The design of the system includes the following three modules (see Figure 8):

Sender (1): Ciciliani uses SuperCollider to send control messages to the system. Alternatively, any (musical) software that is capable of sending Open Sound Control (OSC) messages [19] can be used to communicate with the score system.

Host (2): The host is built on the node.js framework [3] and translates incoming OSC messages to messages that can be transmitted via the WebSocket (WS) protocol. It then distributes these messages to clients connected via (wireless) network. The software uses the node-osc [20] package to receive and process OSC messages and the socket.io [21] package to send WebSockets.

Display (3): Any device that is capable of running a web browser can be used as a client. In the case of the performances of *Anna & Marie*, the devices used were two iPads.

4.2 Desktop Host Application

The host is designed as an app that is available for Linux, iOS, and Windows operating systems. The Electron framework [4] was used to develop the executable app and its GUI. It can be run either on the same computer (localhost) that runs the sound software or on an independent machine. The host application establishes an HTTP-server using the express [22] package for node.js, allowing browsers to connect to the host and to receive the score templates. The goal was to make it as convenient as possible to connect clients via network.

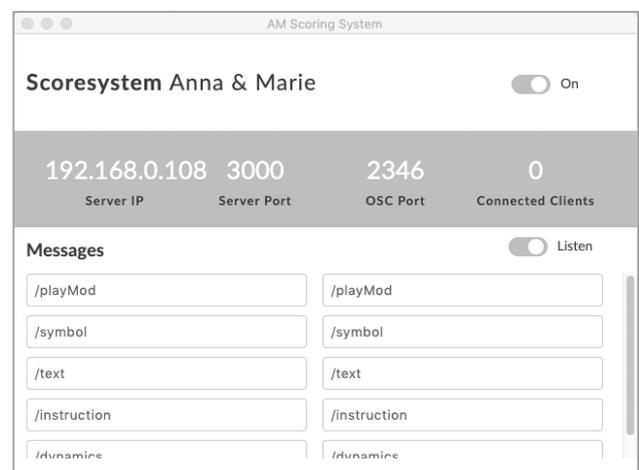


Figure 9. The graphical user interface of the host app.

The graphical user interface (see Figure 9) of the host application allows the configuration of the port number, shows the IP address used as the URL in the browsers of the client tablets, and offers settings to rename incoming OSC messages while translating them to WebSockets. One benefit is that this allows the host to be used not only to convert from OSC to WebSockets, but also to translate incoming commands according to the demands of the given project. A learn function traces all incoming OSC messages and displays them in a list. This is believed to facilitate the process of configuration if it becomes necessary to rename the messages.

4.3 Display for Performers

Any recent web browser can be used to display the score app to the performers in fullscreen-mode. CSS styling creates a floating and centered GUI that is adaptive to different display sizes and resolutions. Vector graphics were programmed using the Snap.svg library [23], making the display independent of resolution and responsive to screen sizes. The score displays the following sections for playing instructions (see Figure 10):

- (1) Arrow symbols. These arrows function as instructions for how the musicians relate to each other in a chamber-musical sense.
- (2) Dynamic symbols.
- (3) Text field for playing instructions.
- (4) Pitch sets for each of the two performers. The pitch sets consist of fragments of 6 different scales based on a microtonal scale.
- (5) The transcription of the narration heard by the audience on the headphones.

Each of the performers are addressed by a separate color.

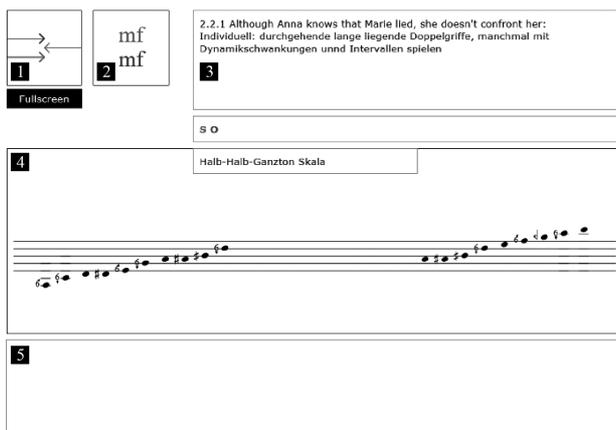


Figure 10. Display of the symbolic score

For the composer, the instructions in the text field (3) made up the main part of the symbolic score and were the key guidelines for the performers. It was essential that the instructions described the way the two musicians were to play music together, which formed the basis for everything

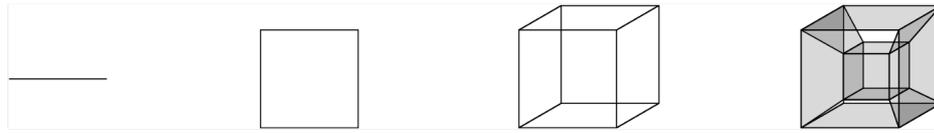
else. After this, more detailed information about the kind of material and playing techniques followed. During the rehearsals, the composer and performers used the text field to take notes on how they negotiated and developed their parts together. This is thought to resemble taking notes and placing marks in printed scores, thus offering a similar feature in a generative score (e.g. by making marks on the touch display, like in apps displaying PDF scores) that could improve the experience and the usability for the performers.

5. CONCLUSION

Recent technological innovations and their widespread availability have allowed composers to invent new ways of combining elements of spatiality and score. This article has argued that both physical and virtual performance spaces can represent a score, and that scores can display characteristics of ergodicity and emergence. Table 1 illustrates a resulting systematic overview of score systems differing in their dimensionality, their medium and the resulting activity of performers.

Several compositions created as part of the GAPPP project display ergodic and emergent characteristics that are related to space in their score systems. These works include, for example, *game over* by Christof Ressi and *Kilgore* by Marko Ciciliani. *Anna & Marie*, however, appears to be in a special category, in which a symbolic real-time score on tablets is generated according to the performers' decisions in the virtual performance space. This results in a close composite of spatial and symbolic score. As both manifestations of the score depend on the basic ruleset of the composition, they are more than just linked. They emerge together in real time, thus differing significantly from the traditional notion of a top-down approach towards a score, which gives decision-making authority to the composer and the score she produces. In the type of score presented here, however, the virtual performance space itself emerges from the ruleset provided by the composition. The notion of a prior text, followed by a technology that reproduces it, is questioned by emergent qualities of scores exemplified by *Anna & Marie*. As the virtual performance space allows the rules of physical reality to be reconfigured, an abstract computational set of rules is provided with the composition. The performers traverse neither a text nor a score. As the performers are asked to move through the virtual space by playing freely according to rules largely determined by the virtual performance space, it is their playing that creates the next iterations of the symbolic score. Here, the performers do not simply traverse the (spatial and symbolic) ergodic score—they produce it at the same time.

The associated decision-making process is not primarily text based as in ergodic literature, but is largely musical, using note duration and pitch to start and make decisions. By taking decisions and traversing the spatial score, the human performers play an essential role in showing and exploring the composition and thereby creating the performance. Thus, performers mediating ergodic emergent scores assume increased agency.



Dimensionality	1-D	2-D	3-D	n-D
Metaphor	Linearity, temporality	Field, map, modularity	Space	Virtual space, arbitrary ruleset
Medium	Mostly Paper	Mostly Paper	Physical Reality	Virtual reality
Examples	Traditional scores	Boulez, Stockhausen	Nine Bells (Tom Johnson)	Anna&Marie, Terrain Study
Effort	Reading	Reading	Acting spatially	Acting spatially

Table 1. Spatial metaphors for notions of scores. (1) linear, one-dimensional. (2) field, map, two-dimensional (3) three-dimensional space (4) n-dimensional virtual space

The presented type of compositions was identified as producing a differentiated type of real-time score. In conclusion, we now will look at how this type fits in the taxonomy of real-time scores developed by Sandeep Bhagwati [24]. Based on Freeman [25], Bhagwati names four categories for real-time music scores:

- Permutational: Existent elements can be reordered by the performer at each performance (see *Constellation-Miroir*).
- Parametric: One or more parameters are left free to the performer.
- Auto-reflexive: The actions of the performer have an incidence on the unfolding of the piece.
- Co-creative: the conductor or the audience may contribute to the interaction with the score.

Bhagwati notes that contemporary real-time scores will to various degrees include aspects of all four categories. However, none of the ones listed would describe the strategies pointed out in this paper adequately. Another category seems necessary to complete the list, a category of real-time scores that exhibit the demonstrated characteristics of ergodicity and emergence:

- Emerging and ergodic: the score (symbolic or spatial) emerges ergodically from the basic rule set of the composition by mediation of the performers.

The suggested additional category classifies scores emerging from compositions that define abstract rules for spaces of possibility. These scores provide the performers

with the agency to mediate the emergence of the work by freely traversing the space of possibility. Analogously to game theory’s notion that the cybertextual process is not equal to reading a text, the process of navigating through a composed audiovisual space by playing an instrument is not equal to reading a score from a sheet of paper. It demands additional effort on the performer’s part, an effort that requires additional choices that in turn lead to a set of consequences. This effort is closer to being active in space than to reading a score. As an activity, it actively contributes to the emergence of one instance of the compositions’ multiple possible instantiations and mediates the entanglement of the score and the *gestalt* of the performance.

This entanglement challenges the notion of the dichotomy of text and technology. It allows the symbolic parts of scores to connect firmly with other parts of the work of art. These parts include the performance space, elements of the game world fulfilling a musical task, game-related playing instructions, and nonhuman agents. By continuous adaptations in real time, the entanglement mediated by the feedback from the performers’ decisions affects the symbolic as well as the spatial score. Future systematic comparisons of different compositions with real-time scores displaying ergodic and emergent qualities may reveal more aesthetic implications of this new proposed category of scores.

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3. REFERENCES

- [1] D. Kim-Boyle, "Visual Design of Real-Time Screen Scores," *Organised Sound*, Volume 19, Special Issue 3, pp. 286-294, 2014.
- [2] U. Eco, *The Open Work*, Harvard University Press, 1989.
- [3] <https://nodejs.org/>
- [4] <https://electronjs.org/>
- [5] R. Gottfried, G. Hajdu, "Drawsocket: A Browser Based System for Networked Score Displa," in *Proceedings of the International Conference on Technologies for Music Notation and Representation*, Monash University, 2019, pp. 55-60.
- [6] G. Hajdu, R. Gottfried, "Networked Music Performance in the Old Elbe Tunnel," in *International Conference on Technologies for Music Notation and Representation*, Monash University, 2019, pp. 15-25.
- [7] <https://unity.com/>
- [8] E. J. Aarseth, *Cybertext - Perspectives on Ergodic Literature*, Johns Hopkins University Press, 1997.
- [9] K. Salen and E. Zimmerman, *Rules of Play: Game Design Fundamentals*, The MIT Press, 2003.
- [10] P. Boulez, D. Noakes and P. Jacobs, "Sonate, Que me Veux-tu?," *Perspectives of New Music*, Vol. 1, No. 2, pp. 32-44, 1963.
- [11] C. Gresser, "Earle Brown's 'Creative Ambiguity' and Ideas of Co-creatorship in Selected Works," *Contemporary Music Review*, Vol. 26, No. 3/4, pp. 377-394, 2007.
- [12] M. Ciciliani, "Virtual 3D Environments as Composition and Performance Spaces," *Journal of New Music Research*, 49:1, pp. 104-113, 2019.
- [13] M. Gardner, "The fantastic combinations of John Conway's new solitaire game 'life'," *Scientific American* 223, pp. 120-123, 1970.
- [14] Gotts, Nicholas M. "Emergent Phenomena in Large Sparse Random Arrays of Conway's 'Game of Life.'" *International Journal of Systems Science* 31:7, pp. 873-94, 2000.
- [15] C. Ressi, *game over. Computerspiel als interaktives Medium für audio-visuelle Kunst*, Master Thesis, 2019.
- [16] <https://vimeo.com/360015209>
- [17] D. Kim-Boyle, "3D Notations and the Immersive Score," *Leonardo Music Journal*, Volume 29, pp. 39-41, 2019.
- [18] <https://supercollider.github.io/>
- [19] M. Wright; A. Freed, "Open Sound Control: A New Protocol for Communicating with Sound Synthesizers," in *Proceedings of the International Computer Music Conference*, 1997.
- [20] <https://www.npmjs.com/package/node-osc>
- [21] <https://www.npmjs.com/package/socket.io>
- [22] <https://www.npmjs.com/package/express>
- [23] <http://snapsvg.io/>
- [24] S. Bhagwati, "Vexations of ephemerality," in *Proceedings of the International Conference on Technologies for Music Notation and Representation*, Coruna, Spain, 2017, pp. 161-166.
- [25] J. Freeman, "Extreme Sight-Reading, Mediated Expression, and Audience Participation: Real-Time Music Notation in Live Performance," *Computer Music Journal* (MIT Press) 32, no. 3, pp. 25-41, 2008.