STARTS Residency Public Report
Cosmologies of the Concert Grand Piano

Aaron Einbond and Jean Bresson

Abstract *Cosmologies* for piano and three-dimensional (3D) electronics explodes the space inside the piano out to the space of the concert hall, situating the listener inside the virtual instrument to experience its secret inner life. The work's interactive electronics connect techniques of audio descriptor analysis and corpus-based synthesis with spatialization using higher-order ambisonics (HOA) and machine learning, enabling the computer to "learn" from measured radiation patterns of acoustic instruments and apply them to spatial audio in real and deferred time. The collaboration joins composer Aaron Einbond with Technical Project OM7/om-spat led by Jean Bresson, along with researchers at the IRCAM STMS laboratory Diemo Schwarz and Jean Bresson. The artistic work was composed for and performed by pianist Alvise Sinivia and produced by IRCAM. The artistic work involved the first use of novel techniques of live spatial sound synthesis and computer-assisted composition, with promising applications for future artistic productions. The project was simultaneously the first fully realized project involving the new OM# environment and its connection to libraries OM-Spat and OM-IAE, and serves as a proof of concept, test case and outcome for this research project. In this way the project harnesses art-science collaboration to generate new techniques for musically expressive goals and to refine these techniques in order to make them available to a wider artistic and research community. Future directions include the release of a series of software tutorials and further art-science research incorporating compact 3D loudspeakers and immersive reproduction of ambient field recordings.

***Index Terms*— ambisonics, audio features, computer-assisted composition, machine learning, situated perception**

I. INTRODUCTION

HOW does a listener know immediately when she or he walks into a room with a live grand piano instead of a recording? One reason is the complex interactions between the piano sound and the space that surrounds it. Artificial Intelligence (AI) research is ubiquitous, yet often ignores the spatial presence of the live instrument and performer. Many AI applications assume a listening environment with stereo loudspeakers or headphones, which can flatten acoustic space. Yet research in the field of music perception points to the essential role of *situated* or *embodied cognition* our listening experience: "cognition as an activity that is structured by the body situated in its environment" (Iyer 2002). "The bodies playing the music […] inform our listening whether subconsciously or consciously" (Walshe 2016). The project *Cosmologies of the Concert Grand Piano* seeks to place the embodied presence of the instrument and its performer at the center of research and creation, using machine learning of audio features to decipher the intricate interdependencies of timbre and space that bring an instrument to life.

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The starting point is the Technical Project *OM7/om-spat* framed by the development of OM# (Bresson *et al,* 2017),[1] "a new generation of computer-aided composition environment, and satellite libraries linking it to state-of-the art music technology components for digital signal processing, spatial audio and machine learning."[2] Based on this project, composer Aaron Einbond proposed an artistic work based on a simple conceptual goal: to situate the listener inside a virtual grand piano. How could this be executed technically and artistically? Past research has elucidated the complex spatial radiation patterns of acoustic instruments (Zotter 2009, p. 89). Attempts have been made to reproduce instrumental models electronically using techniques of higher-order ambisonics (HOA), but these were primarily in a research context rather than artistic creation (d'Alessandro *et al.* 2009; Noisternig *et al.* 2011). In his previous work *Cartographies* for piano with two performers and electronics, Einbond was inspired by these studies to produce a live interactive response to the acoustic piano based on an analysis of its audio features to spatialize electronic sound in the 43.7-channel Klangdom of the Institut für Musik und Akustik at the Zentrum für Kunst und Media (ZKM) in Karlsruhe, Germany (Brümer *et al.* 2014, Einbond 2017).[3] In *Cartographies* the piano is conceived not as a sonic abstraction, but instead as a physical object, prepared with foreign objects and a catalogue of lavaliere and contact microphones, and with which the two performers interact with their full bodies. This approach was carried forward in *Cosmologies;* however, *Cartographies* was not directly based upon measured instrumental radiation patterns.

II. ARTWORK

Cosmologies for piano and three-dimensional (3D) electronics explodes the space inside the piano out to the space around the listener, who is situated inside the virtual instrument to experience its secret inner life. Derived from the Greek word *kosmos*, world, and *logia*, study, the title suggests the microcosm of the piano interior as it expands out to the space of the concert hall surrounding the listener. It also refers to the modern scientific field of physical cosmology, proposing an analogy to the microscopic vibrations from the early universe that expand over billions of years to reach us at the vantage point of our world.

Alvise Sinivia, piano; Hervé Veronese, photograph

The pianist gradually creates his own reality, a sonic microcosm with found materials of contrasting textures and densities. Like a Foley artist or puppeteer, he reaches nearly invisibly inside the instrument to manipulate its metal, wood, and felt. His micro-

[1] https://github.com/cac-t-u-s/om-sharp
[2] https://vertigo.starts.eu/calls/starts-residencies-call-3/residencies/cosmologies-of-the-concert-grand-piano/detail/
[3] A video of the premiere of *Cartographies* at ZKM is available at the following link: youtu.be/XbmGgYoEezU

choreography is magnified by a 3D microphone, expanding to become larger than life as it is projected around the audience with an ambisonic loudspeaker array. The computer "learns" from the spatial presence of the piano and performer, as well as that of other acoustic instruments, to mimic these rich interactions of timbre and space. In the work's final moments, a glimpse of the reality outside the concert hall sneaks in, fusing the piano-world with our own.

The performance is preceded by an interactive installation, a contrasting movement, in which the piano is silent while the spatial microphone is tuned to the ambient sounds of the concert hall and audience. The public is invited to explore the charged space before quietly taking their places as the pianist enters.

Alvise Sinivia, piano; Hervé Veronese, photograph

III. METHODOLOGY

The computer music tools and methodologies developed for the artwork connect audio descriptor analysis and corpus-based synthesis with spatialization using HOA and machine learning techniques. The project harnesses computer programs Max and OM# and associated software packages Spat and MuBu for Max (Schnell *et al.* 2009) along with OpenMusic libraries OM-Spat, OMIAE, and OMAI.

A. Instrument radiation data

Essential data for the project was derived from a database freely distributed by the Technische Universität (TU) Berlin (Weinzierl *et al.* 2017, Shabtai *et al.* 2017) including radiation patterns for 41 orchestral and historical acoustic instruments measured with a sphere of 32 microphones in an anechoic chamber. These data could then be applied to a database of prepared piano recordings produced by Einbond, output using concatenative synthesis techniques (Schwarz 2007), and decoded ambisonically for diffusion with an immersive loudspeaker system.

B. Ambisonic amplification and recording

The TU Berlin data allows the computer to "learn" from the radiation patterns of a variety of acoustic instruments; however, it does not contain data for the piano. To complement the database, recordings and tests were made of the piano in IRCAM Studio 5 using mh acoustic's EM32 Eigenmike 32-channel microphone array. This microphone was then used in performance to reproduce the 3D sound of the piano directly in the ambisonic loudspeaker system, as well as the spatial motions of objects and preparations including aluminum foil, knitting needles, scrub brush, and wrapping paper.

C. OM# and libraries OM-IAE, OM-Spat, and OMAI

The score of *Cosmologies* was prepared using computer-assisted composition (CAC) tools in OM# and Max based on transcriptions of Einbond's piano recordings. The spatial electronics of the work were prototyped using the OM-Spat library (Garcia *et al.* 2016), and the OMAI library (Vinjar and Bresson 2019) was used for deferred-time machine learning to select each piano sound's closest matching instrumental radiation pattern based on audio features describing its timbre.

D. MuBu and Spat packages for Max

Similar processes are performed in real-time with concert patches programmed in Max with the MuBu and Spat packages. The interactive electronics are synthesized and decoded spatially using two computers routed over a Dante audio network and output to a 27.2-loudspeaker ambisonic dome such as the one installed in the Grand Salle of Centre Georges Pompidou for the premiere performance.

IV. CO-CREATION PROCESS

The project proceeded in three phases: the first was a period of research collaboration by the core team of composer Aaron Einbond, tech project principal investigator Jean Bresson, and researchers Diemo Schwarz and Thibaut Carpentier. During this phase background data was gathered and processed, computer music tools were prototyped, and underlying software packages were refined and extended, allowing the tools to reach their final functional forms for use in the artwork. The first phase concluded with sample recording sessions to create an audio database for use in the artwork. The second phase focused on the creation of the composition and its score by Einbond. The third phase included rehearsals and production of the artwork for its public performance by pianist Alvise Sinivia and during the concert IRCAM LIVE in the Grande Salle, Centre Georges Pompidou, Paris, March 5th, 2020. The production team at IRCAM included computer music producer Manuel Poletti, audio engineer Luca Bagnoli, and recording engineer Clément Cerles. During the final phase there were continued contributions by the core team to add software functionality and resolve last-minute bugs in the software tools for OM# and Max.

V. IMPACT

A. Research Impact

Cosmologies has been a unique opportunity for several branches of research and technology developed in the Ircam STMS lab to be put together in the framework of an artistic project. This is, ultimately, the main and most relevant means to assess the quality and success of research and developments in the field of music technology.

It was also one of the first fully realized projects involving the new OM# environment and its connection to Spat (OM-Spat) as core components of the artistic research, and served both as a proof of concept, test case and outcome for this research project. Controlling spatialization in the scope of a compositional process is not an easy task. While high-quality tools currently exist to deal with sound diffusion and room acoustics, no tool allows them to be embedded formally into the composer's workflow, unfolding in time along with other musical parameters and data. This is what the OM7/om-spat project was initially intended to tackle, and what has been pushed one step further in the context of the *Cosmologies* project. By connecting spatialization and concatenative sound synthesis, we also improved the OM# interface with the IAE framework for granular and concatenative sound synthesis, through the OM-IAE library, introducing more control parameters and updated interfaces in the compositional environment. These updated tools are now distributed and available for other users as well.

The OM# environment is now distributed in v1.0 and we hope more users will dive into the advanced controls for sound synthesis and spatialization that the environment has to offer. In addition to OM# and its libraries, the project has contributed new

tools to software packages for the software Max, including patches in the CataRT-MuBu[4] Max Project distributed through the Ircam Forum, as well as added features and bug fixes to objects in the Max Packages MuBu and Spat.

Finally, *Cosmologies* has boosted a current research thread aiming at connecting computer assisted composition (and sound spatialization) to machine learning. Indeed, despite a wide research trend going on in AI and the arts, there exist almost no compositional examples making use of machine learning as a compositional tool, as compared to a means to automatically generate musical pieces or structures. By providing a pioneering and concrete artistic context, this project therefore contributes to shaping this area of research, for which many underlying challenges still remain open.

B. Artistic Impact

Through the art-technology collaboration we describe, *Cosmologies* introduces several novel technological tools into artistic practice for the first time that have promising potential for future exploitation by our team and by other artists and researchers. It is the first application of machine learning to instrumental radiation patterns, permitting the computer to output electroacoustic sound in 3D in reaction to live audio feature analysis. It is the first work to connect concatenative synthesis with higher order ambisonics (HOA), permitting the superposition of an arbitrary number of polyphonic voices to generate richly layered spatial sound synthesis. And it is the first application of the EM32 Eigenmike in a live performance context, permitting an acoustic instrument to be "captured" in 3D and diffused impressively using an ambisonic loudspeaker system. This could be described as "live virtual reality" (VR), suggesting powerful possibilities for artistic practice.

VI. ART-SCIENCE INTER-RELATIONSHIPS

Art-science relationships are the core of the STMS lab hosting this residency. Artistic project initiate, drive and allow the lab to validate its ongoing research. Both the artist Aaron Einbond, and the leader of the Technical Project Jean Bresson, have participated in art-science collaborations before, both through the IRCAM STMS lab and elsewhere. However, what distinguished this collaboration is the time and freedom allowing an unparalleled context to define and build tools that combine our expertise in ways none of us could have imagined alone. The technological results of this collaboration have already been presented in a talk at the IRCAM Forum on March 5th, 2020,[5] and we plan to submit our work in the near future to leading conferences and journals in the field.

VII. FUTURE DIRECTION AND ACTIONS

The immediate next steps for this collaboration are the documentation and distribution of the artwork and software tools: *Cosmologies* was recorded for IRCAM by sound engineer Clément Cerles and will be edited to produce a binaural mix by Cerles and Einbond. Although the immersive spatial effects of the live performance are best experienced live, binaural rendering technology will allow a listener to perceive some of the spatial details while listening through headphones. A professional video will be produced by filmmaker François Vey, which, in combination with the binaural mix, will give viewers an impression of the visual and sonic impact of the live performance.

The software tools developed to produce the artwork currently include a repository of patches for computer programs OM# and Max stored on GitHub. Although the repository is currently private, the authors plan to develop it further into a series of tutorials for public release.

Longer-term goals include the continued development of the project's technical and artistic results. Technically, in terms of software tools, further strategies will be explored to apply machine learning to audio spatialization of instrument radiation

[4] https://forum.ircam.fr/projects/detail/catart-mubu/
[5] https://medias.ircam.fr/embed/media/xafad3c

patterns, and evaluated to compare their results to those employed in *Cosmologies.* Further hardware tools will also be explored: instead of an ambisonic loudspeaker dome as used in *Cosmologies,* and alternative strategy for sound spatialization could be a compact 3D loudspeaker such as the IKO 3D audio speaker by IEM and sonible[6]. This new technology was not practically available at the time of this project; however, it presents promising possibilities for future research. Rather than immersing the listener inside a virtual grand piano, this technology could give the impression of a virtual acoustic source situated in the space with the listener. The research into machine learning of instrumental radiation patterns developed through this project could be applied readily to such a hardware system to model the spatial presence of an acoustic instrument even more realistically.

Artistically, Einbond will continue to explore questions of situated listening in future compositions that respond not only to acoustic instruments, but also to ambient field recordings. This theme is present in the final minutes of *Cosmologies* where a field recording of the Fontaine Stravinsky in Paris, recorded with the EM32 Eigenmike, is projected in the ambisonic loudspeaker dome around the audience, situating them in a spatial reproduction of the urban scene. This idea will be developed in depth in future compositions devoted more extensively to reproducing field recordings in an immersive performance.

VIII. CONCLUSION

The *Cosmologies* project represents a best-case scenario for art-science collaboration, where the synergy of technological research and artistic vision helps both artist and researcher to advance their goals in a direction that neither could have accomplished alone. The response to the premiere performance suggests that this experience was transmitted to the listeners as well, as one reviewer reported: "A composition of 12 minutes that reveals where contemporary music research is situated, the artist being himself composer and performer who works on the relationship between body and instrument. An organic composition bearing the title *Cosmologies,* with sounds that are unrecognizable, completely new, sounds that resonate in the hall, appearing at one angle to be reflected at an opposite angle, like a vapor, thanks to a system of ambisonic diffusion."[7]

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