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# Sonic Interactions in Virtual Environments

Springer

# Human–Computer Interaction Series

Michele Geronazzo · Stefania Serafin
Editors

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# in Virtual Environments

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*Between stimulus and response there is a space. In that space is our power to choose our response. In our response lies our growth and our freedom.*

*—Viktor E. Frankl*

# Preface

Sonic Interaction Design (SID) is the study and exploitation of sound being one of the principal channels conveying information, meaning, esthetic, and emotional qualities in interactive contexts. The field of *Sonic Interactions in Virtual Environments* (SIVE) extends SID to immersive media, i.e., virtual/augmented/mixed reality (XR). Considering a virtuality continuum, this book mainly focused on virtual reality (VR) also facing occasionally mixed and hybrid reality settings.

The basic and most obvious assumption that motivates this volume is: it is hard to live in a world without sound and it is hard in virtual environments (VE) too. VR without plausible and convincing sounds feels unnatural to users. Auditory information is a powerful omnidirectional source of learning for our interaction in real and virtual environments. The good news brought by this book is that VR finally sounds plausible. Advances in several fields are now able to provide an immersive listening experience that is perceptually indistinguishable from reality which means that immersive sounds could make interaction intrinsically natural. Auralization and spatial audio technologies play a fundamental role in providing immersion and presence in VR applications at an unprecedented level. The combination of recent developments in VR headsets and earables further strengthens the perceptual validity of multimodal virtual environments and experiences.

We can therefore promote a true audio-centered and audio-first design for VR with levels of realism and immersiveness that can even surpass the visual counterpart. Visuals, although rightly emphasized by many studies and products, are often not very effectively enhanced and strengthened by sound. The final result is a weakening of multisensory integration and the corresponding VR potentials that strongly determine the quality and durability of the experience.

The editors would like to identify two starting points in the past 10 years that have given rise and awareness to the SIVE research area and studies. The first episode is symbolic: we would like to anecdotally bring back from our memories the first meeting between us, the two editors of the book. The year was 2011, exactly 10 years ago. Michele had recently started his Ph.D. at the Sound and Music Computing Group of the Department of Information Engineering at the University of Padua, under the supervision of Dr. Avanzini. The Italian Association of Musical Informatics

(AIMI) organized the workshop "Sound and Music Computing for Human-Computer Interaction" at the ninth edition of the Biannual Conference of the Italian ACM SIGCHI Chapter (CHItaly) at the beautiful Alghero in Sardinia in early September. A great period for the seaside.

Michele was asked to write his first conference paper to be presented at the workshop entitled "Customized 3D Sound for Innovative Interaction Design," An article with a high-sounding title that promises a lot but provides little: in short, an article of which not to be proud. On the other hand, there were some valuable references to the *egocentric audio perspective* that will be formalized in the introductory chapter of this book. However, the reason why we tell this anecdote is that at his first presentation at a scientific conference for the Ph.D. student Michele Geronazzo, among the very small audience, there was Dr. Stefania Serafin. Ten years ago, we began to discuss issues that connected sonic interaction design with immersive 3D audio in VR. The AIMI president of that time failed to get the workshop's contributions included in the official ACM CHItaly proceedings despite a regular peer-review process. The poor Ph.D. student Michele found himself without an official publication, at his first conference, in an unknown scientific community. We like to think that at that event and with that meeting started something much more relevant and impactful: SIVE. We are here to give it a shape in this book edited and structured together.

Another temporal coincidence brings us to connect this story with the second and official starting point of this adventure. Michele's unpublished conference paper was finally published within his doctoral thesis, defended in 2014, the year in which the *IEEE Virtual Reality* workshop series "*Sonic Interactions in Virtual Environments (SIVE)*" started (https://sive.create.aau.dk/). The mission of IEEE VR SIVE was to increase among the virtual reality community and junior researchers the awareness of the importance of sonic elements when designing immersive XR environments. However, we can also identify a certain degree of reciprocity while considering the fragmented nature and specificity of those studies aim at developing immersive XR environments for sound and music. First, we, therefore, refer to our beloved Sound and Music Computing (SMC) network, and then we consider the International Community for Auditory Display (ICAD), the Audio Engineering Society (AES), and the communities linked to the International Conference on New Interfaces for Musical Expression (NIME), the Digital Audio Effects (DAFX), and the Sonic Interaction Design COST Action (COST-SID IC601, ended in 2012). All these communities address aspects of the SIVE topics according to their specificities. No institutional nor contextual references that collect technological developments, best practices, and creative efforts related to the peculiarities of immersive VEs existed before the SIVE workshop. The book follows a similar philosophy trying to give an exhaustive view of those multidisciplinary topics already mentioned in our two recent reviews.[1] It features state-of-the-art research on real-time auralization, sonic

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[1] S. Serafin, M. Geronazzo, N. C. Nilsson, C. Erkut, and R. Nordahl, "Sonic interactions in virtual reality: state of the art, current challenges and future directions," IEEE Computer Graphics and Applications, vol. 38, no. 2, pp. 31–43, 2018.

S. Serafin et al., "Reflections from five years of Sonic Interactions in Virtual Environments workshops," Journal of New Music Research, vol. 49, no. 1, pp. 24–34, Jan. 2020.

interaction design in VR, quality of the experience in multimodal environments, and applications. We aim to provide an organized starting point on which to develop a new generation of immersive experiences and applications. Since the editors are aware of the very fast social transformation by the acceleration in the development of digital technologies, all chapters should be read as entry points. Future scenarios and solutions will necessarily evolve by combining emerging research areas such as artificial intelligence, ubiquitous and pervasive computing, quantum technologies, as well as continuous discoveries in the neuroscientific field and anthropological reflections on the authenticity of the experience in VR.

For this reason, contributing authors and editors include interdisciplinary experts from the fields of computer science, engineering, acoustics, psychology, design, humanities, and beyond. So that we can give to the reader a broad view and a clear introduction to the state-of-the-art technologies and design principles, and to the challenges that might be awaiting us in the future.

Through an overview of emerging topics, theories, methods, tools, and practices in sonic interactions in virtual environments research, the book aims to establish the basis for further development of this new research area. The authors were invited to contribute to specific topics according to their well-known expertise. They followed a predefined structure outlined by the editors.

The book is divided into four parts:

**Part I, Introduction:** this theoretical part frames the background and the key themes in SIVE. The editors address several phenomenological foundational issues intending to shape a new research field from an archipelago of studies scattered in different research communities.

**Part II, Interactive and Immersive Audio:** we cover the system requirement part with four chapters introducing and analyzing audio-related technological aspects and challenges. With some overlaps and connections, the four chapters deal with the plausibility of an immersive rendering able to tackle the computational burden. To do so, we deal with methods and algorithms for real-time rendering considering sound production, propagation, and spatialization, respectively. Finally, the reproduction and evaluation phase allows closing the development loop of new audio technologies.

**Part III, Sonic Interactions:** a sonic interaction design part devoted to emphasizing the peculiar aspects of sound in immersive media. In particular, spatial interactions are important where we would like to produce and transform ideas and actions to create meaning with VR, as well as the virtual auditory space is an information container that could be shaped by users. As the VR systems enter people's lives, manufacturers, developers, and creators should carefully consider an embodied experience ready to share a common space with peers, collaboratively.

**Part IV, Sonic Experiences:** the last part focuses on multimodal integration for sonic experiences in VR with the help of several case studies. Starting from a literature review of multimodal experiments and experiences with sound, this last part offers some reflections on the concept of audio-visual immersion and audio-haptic integration able to form our ecology of everyday or musical sounds. Finally, the potentials of VR to transport artists and spectators into a world of imagination and

unprecedented expression is taken as an exemplar of what multimodal and immersive experiences can elicit in terms of emotional and rational engagement.

In the following, a summary for each chapter is provided to help the reader to follow the proposed narrative structure.

## Part I

Chapter 1 illustrates the editors' vision of the SIVE research field. The main concept introduced here is the egocentric audio perspective in a technologically mediated environment. The listeners should be entangled with their auditory digital twins in a participatory and enacted exploration for sense-making characterized by a personalized and multisensory first-person spatial reference frame. Intra-actions between humans and non-human agents/actors dynamically and fluidly determine immersion and coherence of the experience, participatively. SID aims to facilitate the diffraction of knowledge in different tasks and contexts.

## Part II

Chapter 2 addresses the first building block of SIVE, i.e., the modeling and synthesis of sound sources, focusing on procedural approaches. Special emphasis is placed on physics-based sound synthesis methods and their potential for improved interactivity concerning the sense of presence and embodiment of a user in a virtual environment.

In Chap. 3, critical challenges in auralization systems in virtual reality and games are identified, including progressing from modeling enclosures to complex, general scenes such as a city block with both indoor and outdoor areas. The authors provide a general overview of real-time auralization systems, their historical design and motivations, and how novel systems have been designed to tackle the new challenges.

Chapter 4 deals with the concepts of adaptation in a binaural audio context, considering first the adaptation of the rendering system to the acoustic and perceptual properties of the user, and second the adaptation of the user to the rendering quality of the system. The authors introduce the topics of head-related transfer function (HRTF) selection (system-to-user adaptation) and HRTF accommodation (user-to-system adaptation).

Finally, Chap. 5 concludes the second part of the book by introducing audio reproduction techniques for virtual reality, the concepts of audio quality, and quality of the experience in VR.

## Part III

Chapter 6 opens the third part of the book devoted to SID within virtual environments. In particular, it deals with space, a fundamental feature of VR systems, and more generally, human experience. In this chapter, the authors propose a typology of VR interactive audio systems, focusing on the function of systems and the role of space in their design. Spatial categories are proposed to be able to analyze the role of space within existing interactive audio VR products.

Chapter 7 promotes the following great opportunities offered by VR systems: to bring experiences, technologies, and users' physical and experiential bodies (soma) together, and to study and teach these open-ended relationships of enaction and meaning-making in the framework of soma design. In this chapter, the authors introduce soma design and focus on design exemplars that come from physical rehabilitation applied to sonic interaction strategies.

Then, Chap. 8 investigates how to design the user experience without being detrimental to the creative output, and how to design spatial configurations to support both individual creativity and collaboration. The authors examine user experience design for collaborative music-making in shared virtual environments, giving design implications for the auditory information and the collaborative facilitation.

Finally, Chap. 9 explores the possibilities in content creation like spatial music mixing, be it in virtual spaces or for surround sound in film and music, offered by the development of VR systems and multimodal simulations. Authors present some design aspects for mixing in VR, investigating existing virtual music mixing products, and creating a framework for a virtual spatial-music mixing tool.

## Part IV

Chapter 10 helps the reader to understand how sound enhances, substitutes, or modifies the way we perceive and interact with the world. This is an important element when designing interactive multimodal experiences. In this chapter, Stefania presents an overview of sound in a multimodal context, ranging from basic experiments in multimodal perception to more advanced interactive experiences.

Chapter 11 focuses on audiovisual experiences, by discussing the idea of immersion, and by providing an experimental paradigm that can be used for assessing immersion. The authors highlight the factors that can influence immersion and they differentiate immersion from the quality of experience (QoE). The theoretical implications for conducting experiments on these aspects are presented, and the authors provide a case study for subjective evaluation after assessing the merits and demerits of subjective and objective measures.

Chapter 12 focuses on audio-haptic experiences, being concerned with haptic augmentations having effects on auditory perception, for example, about how different vibrotactile cues may affect the perceived sound quality. The authors

review the results of different experiments showing that the auditory and somatosensory channels together can produce constructive effects resulting in a measurable perceptual enhancement.

Finally, Chap. 13 examines the special case of virtual music experiences, with particular emphasis on the performance with Immersive Virtual Musical Instruments (IVMI) and the relation between musicians and spectators. The authors assess in detail the several technical and conceptual challenges linked to the composition of IVMI performances on stage (i.e., their scenography), providing a new critical perspective.

We hope the reader finds this book informative and useful for both research and practice with sound.

Udine, Copenhagen                                                    Michele Geronazzo
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