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Schedule for Wednesday, August 22

Time	Room	Plenary Session 3
9:00 - 9:10	Plato	Opening Remarks, AVAR Conference Organizing Committee
9:10 - 10:10	Plato	Keynote Speaker: Ravish Mehra, Facebook Reality Labs *Sound Propagation for Virtual and Augmented Reality*
10:15 - 11:00	Plato	Panel Discussion: *Realistic sound propagation for immersing the user in the virtual environment*
11:00 - 11:25	Cafe	Coffee Break

Time	Room	Paper Sessions	Time	Room	Workshop Sessions
11:30 - 1:00	Michelangelo	Virtual Acoustics & Environment Modeling	11:30 - 1:30	Plato	Dialogue for VR/AR and MPEG-H
1:00 - 2:00	Cafe	Lunch 1	1:30 - 2:30	Cafe	Lunch 2
2:00 - 4:30	Michelangelo	Applications in VR/AR	2:30 - 4:30	Plato	Environments and Spatial Computing
4:30 - 5:00	Cafe	Coffee Break			
5:00 - 7:00	Michelangelo	HRTF Modeling	5:00 - 7:00	Plato	Immersive Audio for VR/AR

Time	Place	Event
7:00 - 10:00	local pubs on 95th street	Mixer at Black Raven and Big Block Breweries

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Plenary Session for Wednesday, August 22

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9:00 - 9:10 Opening Remarks, AVAR Conference Organizing Committee

9:10 - 10:10 Keynote Speaker: Ravish Mehra, Facebook Reality Labs (speaker bio)

Sound Propagation for Virtual and Augmented Reality

Sound propagation is the process of transmission of sound as it is emitted by the source, interacts with the environment and reaches the listener. In the field of VR, realistic sound propagation helps immerse the user in the virtual environment and create a sense of presence. In augmented reality, sound propagation can be used to reinforce the physicality of virtual objects in AR environments by producing sound events that are synchronized with the real world. In this talk, I will discuss sound propagation for interactive applications in VR and AR. I will give an overview of the field of sound propagation and the class of techniques that have been developed over the last three decades. Lastly, I will present a novel sound propagation technique developed at the Oculus Research Lab that has been optimized for generating high-quality acoustics for VR and AR applications.

10:15 - 11:00 Panel Discussion:

Realistic sound propagation for immersing the user in the virtual environment

Sound propagation techniques model the effect of the environment on the sound and predict the acoustic effects of the space from the source position to the final point of arrival at the listener. Realistic sound propagation is crucial in VR applications to immerse the user in the virtual environment and create a sense of presence. Sound propagation effects can make the virtual environment more believable and improve the overall experience of the user. In this panel, we will discuss the current state-of-the-art of sound propagation technologies across the industry and discuss the need for more realistic sound propagation techniques. We will discuss both the physical realism as well the perceptual realism needed for different sound propagation effects in virtual environments.

Panel Members:

- **Ravish Mehra,** *Lead Research Scientist, Facebook Reality Labs*
- **Scott Selfon (Moderator),** *Audio Experiences Lead, Facebook Reality Labs*
- **Nikunj Raghuvanshi,** *Researcher, Microsoft Research*
- **Lakulish Antani,** *Senior VR Audio R&D, Valve Sofware*
- **Ethan Geller,** *Audio Programmer, Epic Games*

About the Keynote Speaker:

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Ravish Mehra, *Lead Research Scientist, Facebook Reality Labs*

Dr. Ravish Mehra is the Lead Research Scientist at Facebook Reality Labs where he is responsible for developing novel techniques to push the state-of-the-art for audio in VR and AR. He completed his PhD in Computer Science at the University of North Carolina at Chapel Hill in the field of acoustics and spatial audio. In his doctoral work, he worked on novel physically-based simulation techniques for simulating complex acoustic phenomena arising out of propagation of sound waves in large environments. His research interests span the fields of audio, acoustics, signal processing, and virtual and augmented reality. Dr. Mehra's work in acoustics and spatial audio has generated considerable interest in the audio community, and his sound propagation and spatial sound system has been integrated into virtual reality systems (Oculus HMD), with demonstrated benefits.

About the Panelists:

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Scott Selfon (Moderator), *Audio Experiences Lead, Facebook Reality Labs*

Scott Selfon is the Audio Experiences Lead at Facebook Reality Labs (formerly Oculus Research), exploring and inventing the technical, creative, and design languages of sound for virtual and augmented reality. Prior to that, he was engaged in developer consultancy, education, and support efforts across three generations of the Xbox game console and broader Windows audio efforts at Microsoft. Scott has composed music for a wide range of media, including film, television, games and live performance, and is a violist with the Puget Sound Symphony in Seattle. A member of the Game Audio Network Guild (G.A.N.G.) advisory board, Scott has been a faculty member of both the Pacific Northwest Film Scoring Program and the University of Southern California, has coordinated and lectured at the Game Developers Conference Audio Boot Camp tutorial sessions for more than fifteen years, and has spoken at the conferences worldwide on audio, interactive entertainment, and real-time sound implementation techniques and technologies. Scott is an alumnus of the University of Southern California, where he obtained dual degrees in music composition (film scoring emphasis) and computer engineering/computer science.

Nikunj Raghuvanshi, *Researcher, Microsoft Research*

Nikunj works at Microsoft Research on computational physics techniques for interactive applications. His main research contribution has been Triton, the first spatial acoustics system to provide accurate wave acoustic effects within the stringent demands of AAA games and AR/VR, shipping in Gears of War 4, Sea of Thieves and Windows 10 mixed reality portal. He has also made contributions in interactive sound synthesis, such as a technique for impact sound variation employed in the AAA game Crackdown 2, and the first real-time physical synthesis system for 2D virtual wind instruments on graphics processors. Nikunj has published and given talks at premiere academic and industrial venues across disciplines: ACM SIGGRAPH, AES, ASA and GDC, where he has also been invited to provide reviews. He has served multiple times on the SIGGRAPH technical papers committee. Before joining Microsoft in 2009, he did his PhD studies at UNC Chapel Hill with a focus on Computer Graphics and physical simulation. His research and code commenced sound simulation as a new direction in the UNC Gamma research group. His entire PhD codebase was licensed from UNC by Microsoft. For more details visit his homepage: www.nikunjr.com

Lakulish Antani, *Senior VR Audio R&D, Valve Sofware*

At Valve, Lakulish is building the technology behind Steam Audio, a cross-platform SDK for VR/AR audio. Through Steam Audio, he is building powerful new ways of creating and interacting with sound in gaming, VR, and AR. By bringing expertise from the world of high-performance, real-time computer graphics, he is working towards building the future of interactive audio. Prior to joining Valve, he was co-founder of Impulsonic, creators of the Phonon SDK for VR audio. Steam Audio and Phonon have been used in several major titles, including Raw Data, Budget Cuts, and Counter-Strike: Global Offensive. Lakulish has a Ph.D. in computer science from the University of North Carolina at Chapel Hill. His dissertation was about novel techniques for precomputing sound propagation in interactive virtual environments. His research interests include interactive sound rendering, real-time computer graphics, GPU algorithms, and parallel programming.

Ethan Geller, *Audio Programmer, Epic Games*

Ethan Geller is an audio programmer working on the Unreal Engine, which is used by several games. Prior to working at Epic Games, Ethan has worked at Dolby and Playstation, received his masters degree from CCRMA at Stanford, and went to undergrad for music composition at Indiana University. Ethans primary interests are HRTF personalization, optimal filter design, and wave field capture/synthesis. He also plays drums.

Paper Session 7

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Virtual Acoustics & Environment Modeling

Room: Michelangelo

Session Chair: Ramani Duraiswami

11:30 - 11:55 Wednesday, August 22

AUTHORS: **Sara R. Martin and U. Peter Svensson,** *Acoustics Research Centre, Dep. of Electronic Systems, Norwegian University of Science and Technology, Trondheim, Norway*

TITLE: **Modeling sound sources with non-convex shapes using an edge diffraction approach**

This paper explores the modeling of sound radiation from vibrating structures, representing the acoustic environment with Green's functions. A fictive convex hull is created that encloses the vibrating structure, and different subdomains will be created at the structure's indents. Each boundary between those subdomains and the convex exterior is then discretized, employing "virtual pistons". The radiation impedance of those virtual pistons can be computed efficiently for the external convex domain with the edge diffraction model in [J. Acoust. Soc. Am. 133, pp. 3681-3691, 2013]. The impedance contributions of the indenting subdomains can be computed theoretically, by means of modal analysis or by any common numerical method. An open shoebox-shaped object is presented and analyzed as an example.

12:00 - 12:25 Wednesday, August 22

AUTHORS: **Anne Heimes, Muhammad Imran and Michael Vorländer,** *Institute of Technical Acoustics RWTH University, Germany*

TITLE: **Real-Time Building Acoustics Auralization of Virtual Environments**

In this study we propose a framework for auralization of sound transmission in virtual buildings and develop the building acoustics filters. This paper describes the calculations for airborne sound insulation metrics based on ISO-12354 and comprehends the auralization process of sound transmission through the flaking paths of building elements. The insulation filters describe the sound transmission between dwellings by partitions and by flanking structures to estimate the transfer functions between the sources and receivers. In Unity 3D, a virtual scenario is created that consists of a multi-storey resident flat with different types of building elements. The sound insulation filters are implemented into virtual scenario to introduce more realism in auralization of buildings acoustics in virtual spaces.

12:30 - 12:55 Wednesday, August 22

AUTHORS: **Keith Godin, Ryan Rohrer, John Snyder and Nikunj Raghuvanshi,** *Microsoft*

TITLE: **Wave Acoustics in a Mixed Reality Shell**

We demonstrate the first integration of wave acoustics in a virtual reality operating system. The Windows mixed reality shell hosts third-party applications inside a 3D virtual home, propagating sound from these applications throughout the environment to provide a natural user interface. Rather than applying manually-designed reverberation volumes or ray-traced geometric acoustics, we use wave acoustics which robustly captures cues like diffracted occlusion and reverberation propagating through portals while reducing the design and maintenance burden. We describe our rendering implementation, materials-based design techniques, reverberation tuning, dynamic range management, and temporal smoothing that ensure a natural listening experience across unpredictable audio content and user motion.

Paper Session 8

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Applications in VR/AR

Room: Michelangelo

Session Chair: Jean-Marc Jot

2:00 - 2:25 Wednesday, August 22

AUTHORS: **Jonathan Mathews and Jonas Braasch,** *Rensselaer Polytechnic Institute*

TITLE: **Real-Time Source-Tracking Spherical Microphone Arrays for Immersive Environments**

Spherical microphone arrays have attained considerable interest in recent years for their ability to decompose three-dimensional soundfields. This paper details real-time capabilities of a source-tracking system composed of a beamforming array and multiple lavalier microphones. Using the lavalier microphones for source identification, a particle filter can be implemented to allow independent tracking of the orientation of multiple sources simultaneously. This source identification and tracking mechanism is utilized in an immersive lab space. In conjunction with networked audiovisual equipment, the system can generate a real-time virtual representation of sound sources for a more dynamic telematic experience.

2:30 - 2:55 Wednesday, August 22

AUTHORS: **Rishabh Gupta, Rishabh Ranjan, Woon-Seng Gan,** *Nanyang Technological University, Singapore*, **Jianjun He,** *Maxim Integrated Product Inc*

TITLE: **On the use of closed back headphones for active hear-through equalization in augmented reality applications**

Augmented Reality (AR) audio refers to techniques where virtual sounds are superimposed with real sounds to produce immersive digital content. Headphones are widely used in consumer devices for playback of virtual sounds. However, for AR audio, an important step is to make sure that headphones allow external sounds to pass through naturally using Hear-Through (HT) processing. In this paper, an investigation of HT design for real sounds using closed-back circumaural headphones equipped with two pairs of microphones was conducted. An adaptive filtering algorithm was used to derive the equalization filter. Experimental result shows close match of the equalized signal to reference open ear listening. Subjective study was carried out to compare the spatial and timbre sound quality of HT mode.

3:00 - 3:25 Wednesday, August 22

AUTHORS: **Karlheinz Brandenburg,** *Fraunhofer IDMT & Technical University Ilmenau, Germany*, **Estefanía Cano, Hanna Lukashevich, Thomas Köllmer,** *Fraunhofer IDMT, Ilmenau, Germany*, **Annika Neidhardt, Florian Klein, Ulrike Sloma and Stephan Werner,** *Technical University Ilmenau, Germany*

TITLE: **Plausible Augmentation of Auditory Scenes Using Dynamic Binaural Synthesis for Personalized Auditory Realities**

Personalized Auditory Realities (PARty) have been introduced at a recent conference (Karlheinz Brandenburg et al.: Personalized Auditory Realities, DAGA 2018, Garching, Germany). In this proposed system, a real auditory environment is analyzed to find separate audio objects. These may be isolated using source separation techniques. Such objects can then be manipulated, virtual sound objects added and the whole scene can be rendered to fit into the real auditory environment. This paper presents the basic idea of PARty and then focuses on the dynamic binaural synthesis system which is used to reproduce ear signals fitting into the real environment. The viability of the system is evaluated for the features localization, externalization, and overall quality in terms of a spatial auditory perception.

Paper Session 8 (continued)

Applications in VR/AR

Room: Michelangelo Session Chair: Jean-Marc Jot

3:30 - 3:55 Wednesday, August 22

AUTHORS: **Andrea Genovese, Gabriel Zalles, Gregory Reardon and Agnieszka Roginska,** *New York University*

TITLE: **Acoustic perturbations in HRTFs measured on Mixed Reality Headsets**

Materials that obstruct the path of acoustic waveforms in free-field to the human ear, may introduce distortions that can modify the natural Head-Related Transfer Functions. In this paper, the effect of wearing commercially available Head-Mounted Displays for Mixed and Augmented Reality has been measured via a dummy head mannequin. Such spectral distortions may be relevant for mixed reality environments where real and virtual sounds mix together in the same auditory scene. The analysis revealed that the measured HMDs affected the fine structure of the HRTF ($>$ 3-6 kHz) and also introduced non-negligible distortions in the interaural level difference range mostly at the contralateral ear. Distortion patterns in HRTFs and cue modifications are reported and discussed.

4:00 - 4:25 Wednesday, August 22

AUTHORS: **Zeynep Özcan,** *Istanbul Technical University*, **Anıl Çamcı,** *University of Michigan*

TITLE: **An Augmented Reality Music Composition Based on the Sonification of Animal Behavior**

In this paper, we discuss the immersive sonification of an artificial ecosystem in the form of an interactive sound art piece, named Proprius. We first offer an overview of existing work that utilizes ecological models in compositional and sonification contexts. We then describe the behavioral and ethological models utilized in Proprius. We evaluate the musical characteristics of animal behaviors, and discuss our approach to sonifying them in the context of an interactive augmented reality composition. We provide details of our system in terms of how it implements ecological simulation, immersive audio, and embodied interaction.

Paper Session 9

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HRTF Modeling

Room: Michelangelo

Session Chair: Ravish Mehra

5:00 - 5:25 Wednesday, August 22

AUTHORS: **Christopher Buchanan,** *Signum Audio, UK*, **Michael Newton,** *Acoustics & Audio Group, University of Edinburgh, UK*

TITLE: **Dynamic Balanced Model Truncation of the Spherical Transfer Function For Use in Structural HRTF Models**

The Spherical Transfer Function (STF) has previously been used in structural HRTF modelling as an analytical approximation to the human head. Versions based on both spherical and spheroidal solid bodies have been incorporated into a range of systems, such as the well known Brown & Duda [Brown 1998] structural model. STF-based models provide a way to simulate frequency dependent head shadowing (ILD) and time delay (ITD) effects, which can form the foundation for structural HRTF representation. We derive and implement a customizable approximation of the STF based on Balanced Model Truncation, and utilize its inherent modular characteristics to synthesize binaural signals from monaural input with relatively low cost implications.

5:30 - 5:55 Wednesday, August 22

AUTHORS: **David Romblom and Helene Bahu,** *Dysonics, San Francisco*

TITLE: **A Revision and Objective Evaluation of the 1-Pole 1-Zero Spherical Head Shadowing Filter**

Structural models of Head Related Transfer Functions attempt to decompose complex acoustic phenomena into constituent signal processing models. The work of Brown and Duda modeled the head with two elements: a pure delay estimated from a ray-tracing formula by Woodworth and a 1-pole 1-zero shadowing filter. The ray-tracing formula is valid for frequencies above ∼2kHz while interaural time delay (ITD) is perceptually significant below ∼1.5kHz. The frequency-dependence of the phase-derived ITDp has been shown by many authors but is not accounted for by ray-tracing assumptions. As such, the shadowing filter must account for the low frequency variation in ITDp. Using a numerical approximation of Rayleigh's solution as a reference, this paper evaluates and revises the work of Brown and Duda.

6:00 - 6:25 Wednesday, August 22

AUTHORS: **Fabian Brinkmann and Stefan Weinzierl,** *Technical University of Berlin, Germany*

TITLE: **Comparison of head-related transfer functions pre-processing techniques for spherical harmonics decomposition**

Head-related transfer functions (HRTFs) are the basis for virtual auditory reality, and a larger number of HRTFs is required for a perceptually transparent representation. Consequently, HRTFs are commonly reconstructed from a reduced data set by means of interpolation. The spherical harmonics transform (SHT), which decomposes HRTF sets into weighted orthogonal basis functions, is an particularly promising approach for this, because it yields a spatially continuous HRTF representation. Because the SHT has to be order truncated in practice, it is of interest to find HRTF representations that concentrate the HRTF energy at low SH orders. This study compares previous approaches to a decomposition based on time aligned HRIRs for their suitability to reduce the required SH order.

Paper Session 9 (continued)

HRTF Modeling

Room: Michelangelo Session Chair: Ravish Mehra

6:30 - 6:55 Wednesday, August 22

AUTHORS: **Faiyadh Shahid, Nikhil Javeri, Kapil Jain and Shruti Badhwar,** *EmbodyVR*

TITLE: **AI DevOps for large-scale HRTF prediction and evaluation: an end to end pipeline**

Bringing truly immersive 3D audio experiences to the end user requires a fast and a user friendly method of predicting HRTFs. While machine learning based approaches for HRTF prediction hold potential, it can be challenging to determine the best workflow for deployment given the iterative nature of data preprocessing, feature extraction, prediction and performance evaluation. Here, we describe an automated, end to end pipeline for HRTF prediction and evaluation that simultaneously tracks the data, code and model, allowing for a comparison of existing and new techniques against a single benchmark.

Workshops 10 & 11

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Dialogue for VR/AR and MPEG-H

Room: Plato

11:30 - 12:25 Wednesday, August 22

Jelle van Mourik, Simon Gumbleton and Nick Ward-Foxton, *Sony Interactive Entertainment Europe*

TITLE: **Recording and implementing dialogue for VR applications**

Rendering voice recordings in a 3-dimensional virtual environment presents many technical and creative challenges, many different from traditional dialogue recording. Based on the learnings from the production of several VR game titles, this talk will discuss an end-to-end workflow of getting dialogue into a VR application. It discusses best-practice techniques with respect to the recording stage. Additionally, all relevant signal paths, such as HRTF processing of the direct sound and reflections, and spatial processing of reverberation are discussed. Particular attention is given to first-person dialogue, which provides an extra challenge, as the lack of proprioception of speech complicates the player's suspension of disbelief that the voice is emanating from themselves. Finally, future improvements and topics for investigation are suggested.

12:35 - 1:30 Wednesday, August 22

Patrick Flangan, *THX Ltd.*

TITLE: **MPEG-H for Gaming AR/VR/MR. Using HOA and Objects to deliver immersive audio.**

A new way to deliver immersive audio for gaming, VR, AR, and MR. Currently the content available on the market is 3 order Ambisonics at best. Here we present MPEG-H that is capable of delivering up 6th order HOA. A fundamental shift to traditional channel-based audio playback where the device say that you must render to 7.1. In the meantime, all the content is consumed on headphones.

Workshops 12 & 13

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Environments and Spatial Computing

Room: Plato

2:30 - 3:25 Wednesday, August 22

Anne Heimes, Muhammad Imran and Michael Vorländer, *Institute of Technical Acoustics RWTH Aachen University*

TITLE: **Real-Time Implementation of Building Acoustic Auralization for Virtual Reality Environments**

We implement a framework for real-time auralization of sound transmission for virtual environments. In Unity 3D, a virtual building is created consisting of a resident flat with different types of building elements. The demo shows real-time airborne sound insulation auralization that comprehends the sound transmission filter for flanking paths of building elements. The insulation filters describe the sound transmission between dwellings by partitions and by flanking structures. The real-time performance of implementation is evaluated in terms of computational costs. Therefore, real-time auralization of virtual buildings is possible for evaluation of acoustics of building structures in immersive manners. This framework allows the users to perform tasks of daily life of work under conditions of usual behavior and movement in virtual reality.

3:35 - 4:30 Wednesday, August 22

Anastasia Devana, *Magic Leap*

TITLE: **The 4 Domains of Audio in Spatial Computing**

Audio techniques for visual media have developed and matured alongside mediums like film, television and video games. Audio professionals in these mediums enjoy established paradigms and sophisticated tools. But the advancement of technologies like Spatial Computing has introduced a brand new medium, with a whole new set of audio challenges, considerations, and possibilities. Creating compelling audio in this medium requires audio designers to change the paradigm or how they think about sound, and to seek out new vocabulary, tools, and processes. In this talk I will introduce the concept of 4 domains of audio, as a prism through which sound designers can address the challenges and take advantage of the unique opportunities of this medium.

Workshops 14 & 15

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Immersive Audio for VR/AR

Room: Plato

5:00 - 5:55 Wednesday, August 22

Tim Gedemer and Francois LaFleur, *Source Sound, Inc.*

TITLE: **Keeping Up With Visual Advances: Creating Innovative Audio for VR/AR - The Struggle is Real**

While the world continues to generate copious amounts of traditional audio / video content, the battle to capture future media consumers is on. With higher quality VR/AR/MR experiences being produced every day, audio must keep up it's end of the bargain by providing sound to match stunning visual advances occurring in these new mediums. This must be realized through the continued advancement of audio technology by researchers and product developers, in concert with the application of that technology by the creative minds working in the field. In this series of three case studies: Pixar's *Coco VR*, Dreamscape's *Alien Zoo*, and CNN's VR news portal, we share information on technical and creative challenges encountered during each project's spatial audio production.

6:05 - 7:00 Wednesday, August 22

Varun Nair, Jon Ojeda, Andrew Boyd, *Facebook*

TITLE: **Immersive Audio At Facebook**

This panel discussion with the Facebook Sound Design and Audio engineering teams will focus on the process of designing audio for immersive media at scale. Four short presentations - sound design process, audio for AR, audio for VR, and audio for 360 media - will be followed by a discussion. The presentations will cover Facebook's unique approach to sound design at scale, lessons in designing immersive audio across a variety of formats and experiences, and the challenges in designing audio at the cutting edge.

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