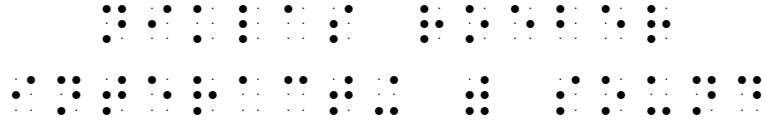


NIKLAS RÖBER

INTERACTION WITH SOUND





# INTERACTION WITH SOUND

EXPLORATIONS BEYOND THE FRONTIERS OF  
3D VIRTUAL AUDITORY ENVIRONMENTS



## DISSERTATION

zur Erlangung des akademischen Grades

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## THESIS ORGANIZATION

The thesis is accompanied by a DVD that contains additional examples that can directly be accessed through the border icons in this pdf. Four different icons are used, which are linked to either sound or video examples, applications, or additional documents, see here also [Appendix C](#). Additionally, color is used to highlight [Bibliographical References](#), and references to certain [Figures, Chapters and Sections](#). These references act as hyperlink and directly connect to the sections referenced. [Turquoise References](#) provide additional links to data folders and examples on the DVD.

With this reading manual in place, I now wish all readers plenty of joy reading and fun with the additional examples and applications!



*Sound Example.*



*Some of the best things emanate from sound,  
— a secret, a vow, a universe*  
— *PRINCE (Musicology) (Prince, 2004)*

*Dedicated to my family, my friends  
and my students.*





## ABSTRACT

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Sound and acoustics both play an important role and are an integral part of our daily life. Most people, however, fail to appreciate how good they really are in interpreting sounds and noises, and are unaware of how much information is really perceived through the auditory channel alone.

This research therefore concentrates on the study of 3D auditory display systems and develops spatial sonification and interaction techniques to support an intuitive exploration of 3D virtual auditory environments. With this goal, techniques from the visual domain are adopted and existing concepts of information visualization are transferred to improve the design and sonification of 3D auditory environments. The focus lies here especially on an audio-centered design that concentrates on the benefits of an auditory display of information. Thereby aspects for an intuitive and natural exploration and interaction are discussed, leading to improvements that also include efficient graphics-based 3D sound rendering and simulation techniques. The thesis explores in this respect several areas of application. These range from interactive 3D audio-only computer games, over the design of augmented audio reality scenarios to the introduction of interactive audiobooks, which integrate interactive elements into audiobooks and radio plays. These applications are prototypically implemented, as well as examined and evaluated in detail through various user evaluations.

Additionally, promising areas of further research are discussed throughout to develop a firm basis for future development.

## KURZFASSUNG

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Sound und Akustik spielen beide eine wichtige Rolle und nehmen in unserem täglichen Leben einen wesentlichen Platz ein. Die meisten Menschen haben jedoch keine genaue Vorstellung davon, wie gut sie Geräusche und Töne hören und interpretieren können, und wissen nicht wieviele Informationen allein durch den Hörsinn aufgenommen werden.

Diese Arbeit konzentriert sich daher auf die Erforschung von 3D akustischen Anzeigen und entwickelt räumliche Sonifikations- und Interaktionsmethoden, welche eine intuitive Erfahrung von 3D virtuellen auditiven Umgebungen ermöglicht. Mit diesem Ziel werden Techniken aus dem visuellen Bereich adaptiert und bestehende Konzepte der Informationsvisualisierung auf die Sonifikation von 3D auditiven Umgebungen übertragen. Einer der Schwerpunkte liegt dabei auf einem akustisch bezogenen Design, welches die Vorteile einer auditiven Darstellung von Informationen hervorhebt. Hierbei werden sowohl die Aspekte für eine natürliche und intuitive Erkundung und Interaktion diskutiert, als auch Techniken für eine verbesserte, Graphikbasierte 3D Soundberechnung und Simulation vorgestellt. Unter diesen Gesichtspunkten untersucht die Arbeit auch verschiedene Anwendungsfelder. Diese reichen von interaktiven 3D Audiospielen, über die Entwicklung von erweiterten akustischen Realitäten, zu der Einführung von Interaktiven Hörbüchern, welche interaktive Elemente in Hörbücher und Hörspiele integriert. All diese Anwendungen sind prototypisch implementiert und mit Hilfe von Nutzerstudien näher untersucht worden.

Weiterhin werden Bereiche die für eine weiterführende Erforschung interessant erscheinen in der gesamten Arbeit diskutiert, um eine starke Basis für zukünftige Entwicklungen zu legen.



*Among the maxims on Lord Naoshige's wall was this one:  
"Matters of great concern should be treated lightly."  
— Master Ittei commented:  
"Matters of small concern should be treated seriously."  
— Tsunetomo Yamamoto (Yamamoto, 1710-1717/2002)*

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---

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## NOTATION

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The following list defines the notation used in this thesis:

$\alpha$	Absorption Coefficient
$\beta$	Diffraction Angle
$\epsilon$	Threshold
$v_{f_j}$	Weighting Factor for Frequency Band $f_j$
$\mu$	Surface Roughness
$\lambda$	Wavelength
$\Phi$	Radiant Power
$\rho$	Media Density
$\tau$	Transmission Coefficient
A	Area
c	Velocity
cm	Centimeter
C	Interaction Data
D	Display Styles
dB	Decibel
$\mathcal{E}$	Enhanced 3D Environment
$E_G$	Geometrical Data
$E_S$	Structural Information
$E_{kin}$	Kinetic Energy
$E_{pot}$	Potential Energy
$E_i$	Incident Energy
$E_e$	Exitant Energy
f	Frequency
$f_j$	Frequency Band j
$f_{update}$	Update Frequency
Hz	Hertz, cycles per second
I	Intensity
$k_d$	Dispersion Error
kHz	Kilo Hertz (1000 Hz)
L	Radiance
$\mathcal{M}$	Enhanced 3D Model

M	Mass
m	Meter
ms	Millisecond
nm	Nanometer
O <sub>S</sub>	Symbolic Information
p	Pressure
r	Radius
s	Second
t	Time
V	Volume
v <sub>J</sub>	Acoustic Pressure

## PUBLICATIONS

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Some ideas and figures from this thesis already appeared previously in the following publications:

[P1] Niklas Röber and Maic Masuch. *“Interacting with Sound: An interaction Paradigm for virtual auditory Worlds.”*, In Proceedings of 10th ICAD Conference, Sidney, Australia, July 2004.

[P2] Niklas Röber and Maic Masuch. *“Auditory Game Authoring: From virtual Worlds to auditory Environments.”*, In Proceedings of CGAIDE Conference, London, England, November 2004.

[P3] Niklas Röber and Maic Masuch. *“Playing Audio-only Games: A compendium of interacting with virtual, auditory Worlds.”*, In Proceedings of the 2nd DIGRA Gamesconference 2005, Vancouver, Canada, June 2005.

[P4] Niklas Röber and Maic Masuch. *“Leaving the Screen: New Perspectives in Audio-only Gaming.”*, In Proceedings of 11th ICAD Conference, Limerick, Ireland, July 2005.

[P5] Niklas Röber, Sven Andres and Maic Masuch. *“HRTF Simulations through acoustic Raytracing.”*, Technischer Report Nr.4, Fakultät für Informatik, Otto-von-Guericke Universität Magdeburg, January 2006.

[P6] Niklas Röber and Maic Masuch. *“Soundpipes: A new way of Path Sonification.”*, Technischer Report Nr.5, Fakultät für Informatik, Otto-von-Guericke Universität Magdeburg, January 2006.

[P7] Niklas Röber, Eva C. Deutschmann and Maic Masuch. *“Authoring of 3D virtual auditory Environments.”*, In Proceedings of Audio Mostly 2006 Conference, Piteå, Sweden, October 2006.

[P8] Axel Berndt, Knut Hartmann, Niklas Röber and Maic Masuch. *“Composition and Arrangement Techniques for Music in Interactive Immersive Environments”*, In Proceedings of Audio Mostly 2006 Conference, Piteå, Sweden, October 2006.

[P9] Niklas Röber, Martin Spindler and Maic Masuch. *“Waveguide-based Room Acoustics through Graphics Hardware.”*, In Proceedings of ICMC 2006, New Orleans, USA, November 2006.

[P10] Niklas Röber, Cornelius Huber, Knut Hartmann, Matthias Feustel, and Maic Masuch. *“Interactive Audiobooks: Combining Narratives with Game Elements.”*, In Proceedings of 3rd TIDSE Conference 2006, Darmstadt, Germany, December 2006.

[P11] Niklas Röber, Ulrich Kaminski and Maic Masuch. *“Ray Acoustics using Computer Graphics Technology.”*, In Proceedings of 10th DAFx Conference, Bordeaux, France, September 2007.

[P12] Cornelius Huber, Niklas Röber, Knut Hartmann and Maic Masuch. *“Evolution of Interactive Audiobooks.”*, In Proceedings of Audio Mostly 2007 Conference, Ilmenau, Germany, September 2007.

[P13] Niklas Röber and Maic Masuch. "*Interaction with Sound in auditory Computer Games.*", In Andy Hunt, "Applications of Gestural Control of Sound: Aiding Movement", 2007.

[P14] Lars Stockmann, Axel Berndt and Niklas Röber. "*A Musical Instrument based on 3D Data and Volume Sonification Techniques.*", In Proceedings of Audio Mostly 2008 Conference, Piteå, Sweden, September 2008.

[P15] Niklas Röber, Ulrich Kaminski, Martin Spindler and Maic Masuch. "*Graphics-based Acoustic Simulations.*", In IEEE Transactions on Visualization and Computer Graphics, (submitted).