APPENDIX

A SHADER CODE EXAMPLES

The examples that are listed in this section emphasize the in Chapter 8 discussed techniques for a more efficient and GPU-based sound rendering and acoustic simulation. The here presented examples are, however, simplified and represent only the *core* of the techniques and algorithms discussed.

A.1 GPU-BASED SOUND SIGNAL PROCESSING

This section explains and discusses several example shaders that are related to Section 8.2, which examined the possibilities for a GPU-accelerated (sound) signal processing. The first example in Listing A.1 shows a resampling routine for sound signals, which also allows to perform a time-scaling of the input data. The signal is stored within a 2D texture with *texSize* being the dimension of this texture, which is passed in as an external parameter. The texture itself is a 32 bit floating point texture and contains the uncompressed sound data. Using a *scale* factor, the new coordinates for texture access are determined and returned: *return coords*, and employed in a second step to perform the actual *sampling*.

```
static const float step     = 1.0 / (texSize - 1);
static const float rowSize  = texSize * step;
static const float pix_size = 1.0 / texSize;

float2 sample(float2 coords, float index)
{
  float scale = 1.0;
  float scaleY = floor(coords.y / pix_size);
  coords.x += scaleY + (index * pix_size);
  coords.x *= scale;
  coords.y = 0.0;

  if (coords.x > 1.0) {
    int up = floor(coords.x);
    coords.x = coords.x - float(up);
    coords.y = coords.y + (up * pix_size);
  }
  if (coords.x < 0.0) {
    int down = abs(floor(coords.x));
    coords.x = coords.x + float(down);
    coords.y = coords.y - (down * pix_size);
  }
  return coords;
}
```

Listing A.1: GPU Signal Processing (Sampling).

A similar sampling is also employed in the example shown in Listing A.2. It displays a small code fragment for creating a chorus-like sound effect. In this example, the original sample is blended with two time-shifted copies of the original signal. To create a chorus effect, an additional *sin* is used depending on the sample's position. This *sweep* factor is

```
float4 chorus(float2 coords : TEX0, uniform sampler2D texture) : COLOR
{
  float sweep = sin(((coords.x/pix_size) + (coords.y*texSize)) / 12000.0);

  float4 s1 = tex2D(texture, coords);
  float4 s2 = tex2D(texture, sample(coords, (-440 - (150 * sweep))));
  float4 s3 = tex2D(texture, sample(coords, (-500 - (200 * sweep))));

  return ((s1+s2+s3)/3.0);
}
```

Listing A.2: GPU Signal Processing (Chorus).

then used to determine the texture coordinates for the actual sampling and the final blending of all three signals: *((s1+s2+s3)/3.0)*.

A last example for a GPU-based signal processing is shown in Listing A.3, and shows an implementation of an equalizer using an additional set of pre-computed bandpass filters. Depending on the filter's center frequency, a certain frequency range of the signal is enhanced or suppressed by the factor *gain*. Although all these examples demonstrate basic signal processing techniques only, more complex filter kernels that support a gathering and scattering of (sound) signal data can easily be realized (Harris, 2005).

```
const uniform float gain;
const uniform float f_center;
const uniform float k_length;

float4 eq_filter(float2 coords : TEX0, uniform sampler2D texture : TEXUNIT0, uniform
     samplerRECT filter :  TEXUNIT1) : COLOR
{
  float4 s1 = tex2D(texture, coords);
  float tmp = 0.0;
  float2 f_coords;
  f_coords.y = f_center;

  for (int i=-k_length ; i<k_length ; i++) {
    f_coords.x = (i+k_length);
    tmp += (texRECT(filter, f_coords)) * (0.5-tex2D(texture, sample(coords, i)).r);
  }

  s1.r = ((s1.r + (gain*tmp)));
  return s1;
}
```

Listing A.3: GPU Signal Processing (Equalizer).

A.2 GPU-BASED 3D WAVEGUIDE MESHES

Section 8.3 discussed 3D waveguide meshes and their application for acoustic simulations. Shader code that implements this technique efficiently in graphics hardware is shown in Listing A.4. It displays the fragment shader for the BCC lattice with phase-reversing reflections enabled at walls and ceilings. It also shows the implementation of a *sound source* in lines 39 – 43, which excites the mesh time-controlled using a given impulse. The first lines 1 – 5 setup several different variables and provide access to the 3D texture, while lines 8 – 11 determine the position of the current node within the texture. The computations of the base grid are shown in lines 14 – 32, while the computations of the offset grid at the cell center are omitted. Their implementation is almost identical to the ones shown for the base grid. Lines 39 – 43 show the excitation of a node using a provided

```
1  uniform float      layer;
2  uniform vec3       step;
3  uniform vec4       impulse;
4  uniform sampler3D  myTexture;
5
6  void main (void)
7  {
8    vec3 stepX = vec3(step.x,0,0);
9    vec3 stepY = vec3(0,step.y,0);
10   vec3 stepZ = vec3(0,0,step.z);
11   vec3 pos   = vec3(gl_TexCoord[0].xy, layer);
12
13   // --- base grid ---- with red=t and green=(t-1) ------------------
14   vec3 posLeft     = pos - stepX;
15   vec3 posLeftDown = posLeft - stepY;
16   vec3 posDown     = pos - stepY;
17
18   vec4 center1   = texture3D(myTexture, pos);
19   vec4 left1     = texture3D(myTexture, posLeft);
20   vec4 leftDown1 = texture3D(myTexture, posLeftDown);
21   vec4 down1     = texture3D(myTexture, posDown);
22
23   vec3 pos0      = pos - stepZ;
24   vec4 center0   = texture3D(myTexture, pos0);
25   vec4 left0     = texture3D(myTexture, posLeft-stepZ);
26   vec4 leftDown0 = texture3D(myTexture, posLeftDown-stepZ);
27   vec4 down0     = texture3D(myTexture, posDown-stepZ);
28
29   float baseGrid = center0.b + left0.b + leftDown0.b + down0.b;
30   baseGrid += center1.b + left1.b + leftDown1.b + down1.b;
31   baseGrid *= 0.25;
32   baseGrid -= center1.g;
33
34   // --- phase shifted grid ---- with blue=t and alpha=(t-1) --------
35
36   shiftGrid = ...
37
38   if (abs(pos.x-impulse.x)<step.x/2.0 &&
39       abs(pos.y-impulse.y)<step.y/2.0 &&
40       abs(pos.z-impulse.z)<step.z/2.0)
41         center1.r += impulse.a;
42
43   if (wall.g >= 8.0)
44     gl_FragColor = vec4(0.0, center1.r, 0.0, center1.b);
45   else
46     gl_FragColor = vec4(baseGrid, center1.r, shiftGrid, center1.b);
47 }
```

Listing A.4: Waveguide Fragment Shader (BCC Lattice).

impulse, while lines 45 – 50 perform the final computations and update the different time frames of the waveguide data according to the principles discussed, refer to Figure 60.

A.3 GPU-BASED RAY ACOUSTIC SIMULATIONS

Additionally, a graphics-based implementation of an acoustic ray tracing system was introduced and discussed in Section 8.4. Listing A.5 shows here the main fragment shader that controls the acoustic ray tracing. First, a sound source is initialized, approximated as a sphere and positioned. Using the current direction and position, several rays are initialized with the actual ray tracing being performed individually and depending on the ray's type. The ray tracing itself along with the intersection tests and the computation of

```
fragOut main( float2 texCoord : TEXCOORD0,
              uniform float3 direction,
              uniform float3 position,
              uniform float3 right,
              uniform float3 soundPos,
              uniform float type )
{
  // init sphere
  sphere s;
  s.position = soundPos;
  s.radius = distance( position, soundPos ) / 16;

  // init ray
  ray r;
  r.origin = position;
  r.len = 0.0;
  r.direction = float3( texCoord.xy, -1.0 );
  r.direction = normalize( r.direction );
  r.direction = mul( getModelViewMatrix( direction, right ), r.direction );
  r.color = createWhiteSpectrum();

  // perform  ray tracing
  fragOut retValue;
  if ( type == REFLECTION )
    retValue = reflection( r, s );
  else if ( type == REFRACTION )
    retValue = refraction( r, s );
  else if ( type == DIFFRACTION )
    retValue = diffraction( r, direction, right, s );

  return retValue;
}
```

Listing A.5: Ray Acoustics Fragment Shader.

the final acoustic energy is performed in separate shader files. At the end, all acoustic energy is accumulated and stored within a 2D texture with two buffers, which is read back to main memory and played back as a native binaural OpenAL stereo sound buffer.

B USER EVALUATIONS AND QUESTIONNAIRES

One of the research's main concern was an evaluation of the developed sonification and interaction techniques to explore and interact with 3D virtual auditory environments. Throughout this research, several tools, techniques and applications have been prototypically implemented and tested. The evaluation of the developed techniques were performed with user studies to examine the implementations more closely. In these evaluations, participants were asked to complete certain predefined tasks. These tests were accompanied by a set of research questionnaires, which had to be answered and filled out before and after the tests.

Chapter 9 discussed all evaluations, as well as presented their major conclusions. The following section summarizes each evaluation in more detail and discusses their initial hypotheses as well as their final conclusions. The evaluations were performed within two user studies, a combined multi-evaluation study and a separate analysis of the augmented audio reality system:

- Combined evaluation study
  - 2D/3D Data- and volume sonification techniques
  - 3D Scene sonification and interaction techniques
  - Evaluation and comparison of audio-only computer games
  - Evaluation of bone-conducting headphones
  - Evaluation of interactive audiobooks
- Augmented audio reality – system and application
  - Pathfinding and -following
  - Augmented audio entertainment (AAR game)

The first five studies were evaluated together as part of a multi user-evaluation, while the last two were setup in the Cathedral of Magdeburg to examine two location-based augmented audio reality implementations. All questionnaires, as well as the SPSS data files can be found on the accompanying DVD, see also Section B.7. As the evaluations were performed in German, the questionnaires and the SPSS evaluations are in German as well. This section, however, translates the most important findings and results to make them more accessible to a broader audience.

Questionnaire "General and demographic Information".

The multi evaluation study started with a general questionnaire to gather common user information and to collect demographic data. A total number of 26 users (23 male, 3 female) participated in these studies, of which 3 had a visual impairment and one user had a slight hearing disability. The distribution in age ranged from 20 to 49, and all participants had at least a high school degree (Abitur).

Analysis of Questionnaires.

Almost all participants had no prior experiences with auditory display systems or audio-only computer games. This makes these evaluations even more interesting, as it allows an assessment of the developed techniques using an unbiased audience. However, around 60% of the participants had a fundamental knowledge of 3D interaction and are playing computer games on a regular basis. This knowledge makes an interaction with 3D virtual auditory environments, as well as the performance of the required tasks much more easy.

B.1 2D/3D DATA- AND VOLUME SONIFICATION TECHNIQUES

This first section discusses the evaluation of the in Section 5.3.1 developed 2D/3D data and volume sonification techniques. The main results of this user evaluation were presented in Section 9.2 and have been discussed together with several examples. The goal of this evaluation was to assess the potential and the functionality of the developed techniques, as well as to determine the efficiency of their application. Prior to the user analysis, several hypotheses have been postulated to focus on and examine specific parts more closely:

- Sonification techniques are sufficient to acoustically display simple 2D/3D data sets
- Some techniques (sound spatialization, rhythm, melodies etc.) enhance the perception and allow a finer stream segregation
- A combined audio/visual examination of data sets is more efficient and thorough than a clean graphics-based data visualization
- Spatial interaction techniques thereby greatly improve the understanding of the data set and its topology

Questionnaire "Data and Volume Sonification".

Analysis of Questionnaires.

The questionnaire to analyze and proove/disproove these hypotheses was grouped into five sections, in which each section was further divided into individual tasks:

- Classification of melody and rhythm
- Evaluation of stock data sonification techniques
- 2D Shape sonification
- 3D Object sonification
- 3D Volumetric data sonification

The first task was based on a personal rating of four different melodies to gather information of how one perceives, appreciates and interprets different melodic rhythms. The second task included a listening to three different stock sonifications, in which the participants had to identify the correct number of parallel stock data sonifications, as well as had to draw an estimate of the ascending and descending stock graph figures. Although the last example that was sonified was also the most complex, yet it utilized two techniques that allowed a better segregation of parallel sound streams. Therefore, most participants performed here at

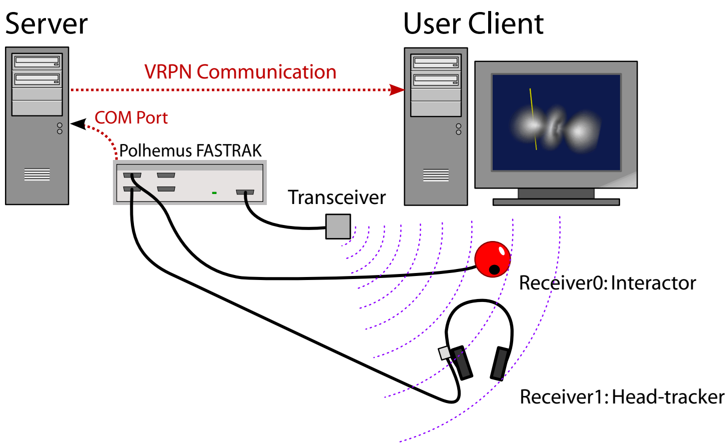

Figure 92: User Evaluation Setup.

best. The third and the fourth task were centered around the sonification of various 2D shapes and 3D objects that the participants had to identify correctly. The last task comprised the sonification of three volumetric data sets, in which the listeners had to visually identify the data set, draw an estimate of its density distribution, as well as assess the benefits of a combined audio/visual data visualization and sonification.

The setup for this evaluation was as follows, and is illustrated in Figure 92:

- Three desktop computer systems:
  - One computer for the evaluation of the 2D sonification techniques
  - One computer for the evaluation of the 3D sonification techniques
  - One control computer for the tracking system
- Two regular HiFi headphone systems
- One tracking system (Polhemus FASTRAK plus the 3Ball sensor)

The conclusions to be drawn from this evaluation are that all sonification techniques performed even better than anticipated, and that all initial hypotheses could be confirmed. A total of 15 participants (14 male, 1 female) were involved in this evaluation, of which two had a vision impairment and one a slight hearing deficiency. More details can be found in the analysis of the questionnaires. The evaluation of the stock market data sonifications clearly show a much better performance of the participants through the added sound spatialization, especially when combined with an additional rhythmic sequencing. The sonification of 2D shapes and 3D objects performed well as well, although some shapes/objects had a similar auditory resemblance and were sometimes misinterpreted (eg. sphere/cylinder). The sonification of volumetric data sets proved that even more difficult volumes can here be identified correctly. An added spatial sonification and exploration allows thereby a better understanding of the data's inherent topology. A combined data sonification/visualization achieved overall the best performance.

B.2 3D SCENE SONIFICATION AND INTERACTION

The second user study examined several of the in Section 5.3.2 and Section 5.4 developed 3D scene sonification and interaction techniques. The evaluation was previously discussed in Section 9.3, which also presented the major results and conclusions. The goal was to assess the functionality and applicability of the devised techniques and to examine the performance of users in an exploration of 3D virtual auditory environments. The postulated hypotheses for this evaluation are:

- An orientation, navigation and exploration in 3D virtual auditory environments is easily possible with adequate 3D scene sonification and interaction techniques
- A selective listening (auditory lens) allows a better perception and understanding of the environment
- Head-tracking and sound spatialization improve perception and navigation
- Speech analysis and synthesis are both only partially applicable
- The interaction with a 3D ring based menu system can be performed trough
  - Earcons and/or speech for information sonification
  - 3D Gestures and standard (gamepad) interactions

The evaluation and questionnaire to examine these questions were grouped into five sections:

- 3D Scene – navigation and orientation
- Selective 3D scene sonification – examination of the auditory lens
- Navigation and pathfinding through a complex 3D auditory environment
- Speech-based 3D scene interaction and sonification
- Interaction with a 3D auditory ring menu system

Questionnaire "3D Scene Sonification".

Analysis of Questionnaires.

Each section thereby concentrated on a specific task that was explained and demonstrated using a short example prior to the evaluation. The first task utilized the sound stage, as is depicted in Figure 93, in which the participants had to explore a 3D auditory environment with the techniques provided to find and activate four different sound sources. Additionally, an overview of the perceived scene topology had to be drawn. The interaction was based on 3D head-tracking and a navigation/orientation using a regular gamepad. The second task was dedicated to the selective listening approach provided by the auditory lens metaphor. In this evaluation, a more complex scene was used, which the participants had to explore utilizing the auditory lens. This lens could be switched on/off, as well as several parameters, eg. selective listening, could be adjusted. The third task employed a complex environment with 12 different sound sources, in which the user had to navigate to a specific sound source (alarm sound) without colliding with other sources. The forth task evaluated the possibilities of a speech-based interface, in which the navigation and scene interaction were mapped to speech commands. The scene sonification itself was also mapped to speech and provided by speech synthesis. In the last task, the participants were asked to interact with a 3D auditory ring-based menu system. Here the gamepad was used for interaction, as well as the Stylus to input basic 3D gestures.

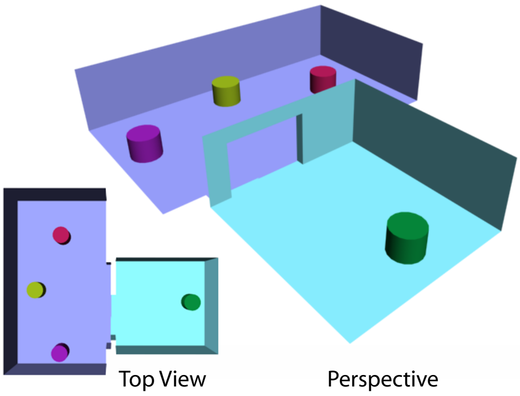

Figure 93: The Sound Stage.

The evaluation of these techniques also required 3D head-tracking and spatial interaction capabilities, and therefore, a similar setup as in the previous section, and as depicted in Figure 92, was used:

- Two desktop computer systems:
  - One computer for the evaluation of the 3D scene sonification and interaction techniques
  - One control computer for the tracking system
- One HiFi headphone system with a microphone for speech input
- One tracking system (Polhemus FASTRAK plus the Stylus sensor)
- One gamepad for regular interactions

14 users (13 male, 1 female) participated in this user evaluation, of which two had a slight visual, as well as one a slight hearing impairment. The majority of the participants ($\geqslant$ 70%) had a high familiarity with 3D interaction techniques, with a few users also being experienced with auditory displays and audio-only computer games ($\leqslant$ 20%). The majority of all users accomplished the tasks without larger difficulties, while two participants (not included in the evaluation) had considerable problems in interpreting and localizing virtual 3D sound sources. These difficulties most likely result from the use of generalized HRTFs, which are not applicable to every individual. All techniques that were evaluated, the auditory lens, as well as several methods for scene sonification and spatial interaction, have proven their applicability towards an interaction and exploration of 3D virtual auditory environments. Especially the integrated head-tracking and the spatial interaction techniques were of high assistance. A complete overview of the evaluation results can be found in the analysis of the questionnaires.

B.3 EVALUATION AND COMPARISON OF AUDIOGAMES

The audio framework devised in Chapter 5 was designed specifically with 3D audio-only computer games in mind. Section 9.4 analyzed and discussed several existing audiogames and compared them with four implementations that are based on this framework. These audiogames utilize 3D sound spatialization, as well as employ head-tracking and spatial interaction techniques. The goal of this evaluation was to explore the potential of an audio-centered gameplay and to assess the applicability of the previously evaluated 3D scene sonification and interaction techniques towards an employment in audio-only computer games. The hypotheses for this evaluation are:

- An audio-centered gameplay is more enjoyable than an adaptation of a visual genre
- Spatial interactions and 3D head-tracking improve the perception and the playability of a 3D audiogame
- Efficient and high-quality 3D sound spatializations are required
- An audio-only gameplay is highly immersive
- Audiogames can be played and enjoyed by unexperienced and sighted users as well

Questionnaire "Audiogames".

Analysis of Questionnaires.

In this evaluation, several audiogames were played and compared in terms of playability, scene sonification, immersion, fun, and more. The majority of participants thereby played several of these games. The questionnaire used was divided into two sections and designed to examine each game in more detail, see also Section B.7:

- General classification of the game
- Interaction and scene sonification

The first part was used to answer more general questions regarding the difficulty and the gameplay itself, while the second part explicitly focussed on the sonification of information and the interaction with the game environment. The participants could thereby play a title for as long as was required to be able to assess the game and to answer the questionnaire.

The play of the regular games required a standard PC only, while the four games that are based on the audio framework required additional hardware to perform spatial interactions. The setup is here similar to the previous evaluations, and as depicted in Figure 93:

- Three desktop computer systems:
  - One computer for the evaluation of regular audiogames
  - One computer for the evaluation of the audiogames that utilize 3D head-tracking and spatial interaction
  - One control computer for the tracking system
- Two regular HiFi headphone systems
- One tracking system (Polhemus FASTRAK with the Stylus sensor)
- Two gamepads for regular interaction

The conclusions to the analysis and comparison of several audiogames can be found in Section 9.4.3, which already stressed the issues for a *rethinking of audiogames* towards a more audio-centered interaction and gameplay. 13 users (12 male, 1 female) participated in this user evaluation, of which two had a slight visual and one a slight hearing impairment. Two participants had no prior experiences with computer games, while three users where also familiar with an auditory gameplay. The participants played and evaluated six games, of which the ones that are ranked highest were also played most often:

- Mosquito (played 11 times)
- Audio Frogger (played 9 times)
- The hidden Secret (played 5 times)
- Der Tag wird zur Nacht (played 5 times)
- Terraformer (played 3 times)
- Shades of Doom (played 3 times)

Interesting to note is that the games with the simplest gameplay (*Mosquito*) were also the ones that were enjoyed most. All of the proposed hypotheses could be confirmed and it was shown that 3D sound spatialization and an audio-centered gameplay are more desirable than an adaptation of audio/visual games. The speech input and output of *AudioQuake* annoyed so many participant that it was excluded from the analysis. Several titles, such as *The hidden Secret* and *Der Tag wird zur Nacht*, concentrated on a strong storyline that was appreciated by all players and found to be very immersive. More details of this evaluation, specifically to each game, can be found in the analysis of the questionnaires.

B.4 EVALUATION OF BONE-CONDUCTING HEADPHONES

The in Chapter 6 devised augmented audio reality system requires a proximaural sound presentation that allows a simultaneous perception of both, the real and the virtual auditory environment. Bone-conducting headphone systems represent here a very promising approach, as this technology does not cover the ears, and hence, does not influence the perception and localization of natural sound sources. Artificial sound sources are perceived via skin and bone, thus *providing a second pair of ears*. Section 9.5.1 presented and discussed the main results of a user evaluation to determine if *bonephones* are really applicable for the perception of 3D auditory environmental information and 3D virtual sound sources. To evaluate this, a direct comparison with regular HiFi headphones was performed. The hypotheses of this evaluation are:

- Sound perception using bone-conducting headphone systems probably causes partial impairments at certain levels of loudness and for certain frequency ranges, with
  - Expected difficulties for low loudness levels
  - Expected difficulties at very low, and very high frequency ranges
- Bone-conducting headphones can be employed for the perception of environmental acoustics and to localize virtual 3D sound sources
- Bone-conducting headphones perform qualitatively similar in the perception of speech, but overall less for music and high-quality acoustics

The task therefore was to let participants listen to both headphone systems and assess to what they have heard. The participants would start here with either the bonephones or the regular HiFi headphones and perform a series of tests and sound quality assessments:

- Perception of varying loudness levels
- Perception of varying frequency ranges
- Perception and quality assessment of different speech, music and environmental acoustic samples
- Source localization of stationary and dynamic 3D virtual sound sources

Questionnaire "Bonephone Evaluation".

Analysis of Questionnaires.

The first test presented a sine tone at different loudness levels to assess what levels of loudness are audible on both headphones. The second test was similar and employed a tone with a constant loudness, but with a varying frequency range. The third test required the participants to rate the perceived quality of several sound, speech and acoustic samples, while the forth task was centered around the localization of stationary and dynamic 3D virtual sound sources. The dynamic sound sources thereby moved along a quarter sphere, ie. from the front to left. No 3D head-tracking was employed, although this would have clearly improved the perception of the dynamic 3D sound sources.

The setup of this evaluation only required a regular desktop computer system with sound output and the possibility to connect two headphone systems:

- One desktop computer for the evaluation of both headphones
- A regular HiFi headphone system
- A bone-conducting headphone system

The test itself was implement using different Powerpoint slides, which explained each test individually, as well as presented the respective sound samples for listening, refer to Appendix C.

In this evaluation, 16 users (13 male, 3 female) participated, with two persons having a slight visual, as well as one a slight hearing impairment. The short conclusion of this evaluation is that bone-conducting headphone systems can be very well applied for the display of 3D virtual auditory environments, as well as employed within an augmented audio reality system. Although the acoustic quality perceived is slightly lower compared to regular HiFi headphones, it does not impede with the perception and localization accuracy of virtual 3D sound sources. In fact, the accuracy of the two systems was almost identical for both, stationary and dynamic 3D sound sources. However, the loudness and frequency evaluations revealed as expected a drop at lower loudness levels as well as for lower frequencies. These facts must be considered for the design of a 3D augmented auditory environment that is presented using bone-conducting headphones. More details of this evaluation can be found in the analysis of the questionnaires.

B.5 EVALUATION OF INTERACTIVE AUDIOBOOKS

Throughout the research it was assumed that an audio-only presentation permits a stronger and deeper immersion than a combined audio/visual representation of a virtual scene. Therefore, Section 9.6 developed the concept of interactive audiobooks, which combines the narrative principles and story representations from audiobooks and radio plays with interactive elements from adventure computer games. Two example stories were prototypically implemented and also evaluated using a user evaluation (Röber et al., 2006b; Huber et al., 2007). These early evaluations, however, have shown several issues within the user interface and the means to interact with the storyline. Consequentially, the concept was revised and a second prototype evaluated with the following hypotheses:

- Interactive audiobooks permit a high level of immersion
- The interface designed is intuitive and easy to use
- The non-linearity of the underlying storyline is perceived and understood
- The play of integrated minigames enhances the perception of the story, as well as increases the level of immersion
- The varying degree of interaction is perceived as seamless

Questionnaire "Interactive Audiobooks".

Analysis of Questionnaires.

The participants could choose to play the first quarter only, or the entire storyline of the interactive audiobook of *"The hidden Secret"*, see also Section 9.6. After the evaluation and the interaction with the audiobook, all participants were asked to answer several questions. The questionnaire was grouped into the following three sections:

- General perception and classification of interactive audiobooks
- Storytelling and narration
- Story interaction and play of the included minigames

The first questions were centered around the general perception of the concept and how well users could interact with the system. The second and third part focussed on specific areas of interactive audiobooks, in which part two concentrated solely on storytelling and narration and part three on the interaction with the included minigames.

The setup for this evaluation was very simple and required a desktop computer system with sound output, a good pair of headphones, as well as a gamepad for the interaction:

- One desktop computer system
- One regular HiFi headphone system
- One regular gamepad for story interaction and play of the minigames

The results of this evaluation confirm the previous analyses and further emphasize the high applicability of auditory environments for storytelling and narration (Röber et al., 2006b; Huber et al., 2007). Although only 7 users (6 male, 1 female) participated in this evaluation (due to the long stories), the results are, nevertheless, meaningful, as the findings orient themselves along those of the previous studies. All participants but one experienced the entire storyline and immersed themselves into the presented story arc. Interesting to note is that only a few participants appreciated the non-linearity of the storytelling, which is most likely due to the fact that the audiobook was only heard once. The interaction with the new designed interface also appears to be much more intuitive, as almost no one missed any of the interactive parts, which was the case with an earlier implementation (Röber et al., 2006b). More details and results can be found in the analysis of the questionnaires.

B.6 AUGMENTED AUDIO REALITY - SYSTEM AND APPLICATION

This last evaluation was performed individually and at a different location. Chapter 6 discussed in detail the concept of augmented audio reality and devised a low-cost system for its realization. The main goal of this user evaluation was a performance analysis of the entire system to determines how well the developed components operate, as well as how good the authored content is perceived. Section 9.5 already discussed and presented here the major results of this evaluation. The main research questions and hypotheses for this evaluation were:

- Evaluation and assessment of the systems overall performance
  - Accuracy of the WiFi-based user positioning
  - Orientation accuracy, ie. the performance of the 3D head-tracking
  - Efficiency and accuracy of the 3D pointing technique utilizing the gyro mouse
- Perception and experience of the auditory overlay, ie. how well are both, the virtual and the artificial, environments perceived as one?
- Expressivity, effectiveness and performance of the employed sonification and interaction techniques
- Presentation and perception of the storyline (immersion)

Questionnaire "Augmented Audio Reality".

Analysis of Questionnaires.

To evaluate the system and its application, two example scenarios have been authored using the environment discussed in Chapter 7. The chosen scenarios required a setup and evaluation of the system within the Cathedral of Magdeburg, refer also to Section 9.5.2. The evaluation itself and the questionnaire used were thereby divided and grouped into three main sections:

- General perception and classification of the augmented audio reality system
- Scenario 1 – Path-tracking and -following
- Scenario 2 – Play and interaction with the augmented audio reality game *"The hidden Secret"*

The first section assessed the general perception and performance of the augmented audio reality system, while the second and third part explicitly concentrated on the two example implementations. Scenario 1 required the tracking and following of a virtual path that was sonified acoustically, while Scenario 2 allowed a partial interaction with the story of *"The hidden Secret"*, this time in its augmented audio reality implementation and played *on location*.

The evaluation of the AAR system along with its application required the largest setup of all evaluations. The radiomap that was employed for the WiFi-based user positioning was measured in advance. The hardware that was employed in this evaluation was:

- One wearable computer system (laptop), equipped with

  - One set of bone-conducting headphones for sound presentation
  - One gamepad for regular interaction
  - One gyro mouse for 3D pointing and 3D interaction
  - One digital compass employed for 3D user head-tracking
  - One WiFi computer card equipped with an external antenna for user positioning
- Nine portable WiFi access points

An extensive analysis and discussion of the results was already provided in Section 9.5.3. A short conclusion of the here developed AAR system is that the system works very well, with an exception being the WiFi-based user positioning. A total number of 13 users (10 male, 3 female) participated in this evaluation, of which three were completely blind. The range in age was between 20 and 59 and the majority of users had no or limited experiences with 3D interactions and auditory display systems. Overall, the system and its functionality was perceived very well, but the inaccuracies of the user positioning also impaired the perception of the other functions. A special analysis tool, however, revealed that all other components performed as expected, refer to Section 9.5.3. More details on the evaluation of this study can also be found in the analysis of the questionnaires.

B.7 QUESTIONNAIRES

The following pages show exemplarily two questionnaires:

- Questionnaire “General and demographic Information” on page 189
- Questionnaire “Evaluation of Audiogames” on page 193

Questionnaire "General and demographic Information"

Fragebogen – Allgemeiner Teil

Nummer:__________

(1) Normalsichtig ☐ Sehbehindert ☐ Blind ☐

(2) Hörbeinträchtigung keine ☐ links ☐ rechts ☐

(3) Geschlecht männlich ☐ weiblich ☐

(4) Alter 10-19 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐

(5) Ausbildung / Bildungsstand ____

(6) Beruf / Tätigkeit ____

(7) Wie gestalten Sie Ihre Freizeit?

(8) Ich sehe Filme *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(9) Ich sehe Fernsehen *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(10) Ich höre Musik (CDs, MP3, etc.) *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(11) Ich höre Radio *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(12) Ich spiele Computerspiele *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(13) Ich lese Bücher *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(14) Ich höre Hörbücher *gar nicht* ☐ ☐ ☐ ☐ ☐ *sehr oft*

(15) Computerkenntnisse *keine* ☐ ☐ ☐ ☐ ☐ *sehr hoch*

(16) Erfahrung mit 3D Interaktion *keine* ☐ ☐ ☐ ☐ ☐ *sehr hoch*

(17) Erfahrung mit auditiven Displays *keine* ☐ ☐ ☐ ☐ ☐ *sehr hoch*

(18) Computerspielkenntnisse *keine* ☐ ☐ ☐ ☐ ☐ *sehr hoch*

(19) Erfahrung mit Audiogames *keine* ☐ ☐ ☐ ☐ ☐ *sehr hoch*

Beispiel: *nein* ☐ ☒ *ja* , entspricht **ja**

Beispiel: *sehr schlecht* ☐ ☐ ☐ ☒ ☐ *sehr gut* , entspricht **gut**

Nutzerstudien – Übersicht

2D/3D Sonifikation und Interaktion

- Allgemeine 3D Sonifikation- und Interaktionstechniken
- 2D/3D Daten und Volumen Sonifikation
- Sprachsteuerung eines Abenteuer-Computerspiels

Wahrnehmung (Bonephones)

- Sound Wahrnehmung mit normalen Kopfhörern und Knochenschall-Kopfhörern

Audiogames

- Echte 3D Audiogames
- Klassische Audiogames

Interaktive Hörbücher

- Evaluation eines *Interaktiven Hörbuches*

Was gefiel Ihnen am Besten? ____

Was gefiel Ihnen überhaupt nicht? ____

Weitere Anmerkungen, Hinweise, Probleme:

____
____
____
____
____
____

Questionnaire "Evaluation of Audiogames"

Fragebogen – Audiogames

Nummer: __________

Spiel:

- ☐ Mosquito
- ☐ Audio Frogger
- ☐ Dom Saga
- ☐ Matrix Shot
- ☐ Seus Crane – Detective for Hire
- ☐ Der Tag wird zur Nacht
- ☐ Terraformer
- ☐ Shades of Doom
- ☐ Audio Quake

Weitere Anmerkungen, Hinweise, Probleme:

____

____

____

____

____

____

Teil1: Allgemeiner Teil

(1) Persönliche Einordnung des Spiels in Genre: (Mehrfachnennung möglich)

☐ Actionspiel	☐ Geschicklichkeit	☐ Sportspiel
☐ Adventure	☐ Puzzle/Quiz/Rätsel	☐ Rennspiel
☐ Rollenspiel	☐ Ballerspiel	☐ Audiogame

(2) War das Ziel des Spiels klar?	*unklar*	☐ ☐ ☐ ☐ ☐	*klar*
(3) Wie hoch war der Schwierigkeitsgrad des Spiels?	*zu schwer*	☐ ☐ ☐ ☐ ☐	*zu leicht*
(4) Hat es Spaß gemacht?	*überhaupt nicht*	☐ ☐ ☐ ☐ ☐	*sehr viel*
(5) Persönliche Bewertung der Spielidee?	*sehr schlecht*	☐ ☐ ☐ ☐ ☐	*sehr gut*
(6) Würde man es wiederspielen oder weiterempfehlen?	*best. nicht*	☐ ☐ ☐ ☐ ☐	*auf alle Fälle*
(7) Unterhaltsamkeit	*sehr schlecht*	☐ ☐ ☐ ☐ ☐	*sehr gut*
(8) Wie ist die akustische Gestaltung der Szenen?	*sehr schlecht*	☐ ☐ ☐ ☐ ☐	*sehr gut*
(9) Wie ist die akustische Qualität allgemein?	*sehr schlecht*	☐ ☐ ☐ ☐ ☐	*sehr gut*

Teil2: Interaktion und Sonifikation

(10) Fiel es Ihnen schwer die einzelnen Geräusche zu identifizieren?

sehr schwer ☐ ☐ ☐ ☐ ☐ *sehr leicht*

(11) Konnten Sie die Geräusche lokalisieren (3D)? *sehr schwer* ☐ ☐ ☐ ☐ ☐ *sehr gut*

(12) Wie war die Präsentation von Spiel-Informationen? *s. schlecht* ☐ ☐ ☐ ☐ ☐ *sehr gut*

(13) Wussten Sie jederzeit wo Sie sich im Spiel befinden und was Sie dort machen können?

nie ☐ ☐ ☐ ☐ ☐ *immer*

(14) Gab es knifflige Situationen wo Sie nicht weiterwussten? *nie* ☐ ☐ ☐ ☐ ☐ *immer*

(15) Wie gut war die Akustik des Spiels (Simulation der Umgebung)?

sehr schlecht ☐ ☐ ☐ ☐ ☐ *sehr gut*

(16) Konnte man es gut mit den Kopfhörern spielen? *sehr schlecht* ☐ ☐ ☐ ☐ ☐ *sehr gut*

(17) Wie war die Steuerung des Spiels? *zu schwer* ☐ ☐ ☐ ☐ ☐ *zu leicht*

(18) Wie gut funktionierte die 3D Soundwahrnehmung? *s. schlecht* ☐ ☐ ☐ ☐ ☐ *sehr gut*

Fragebogen – Audiogames (Betreuer)

Nummer: __________

Es gab technische Probleme *nein* ☐ *ja* ☐

Wenn ja, welche: ______________________________

Es gab Schwierigkeiten mit der Interaktion / Steuerung *nein* ☐ *ja* ☐

Wenn ja, welche: ______________________________

Es gab Schwierigkeiten bei der auditiven Wahrnehmung *nein* ☐ *ja* ☐

Wenn ja, welche: ______________________________

Fand das Spiel doof, langweilig oder schlecht *nein* ☐ *ja* ☐

Begründung?: ______________________________

Es hat offensichtlich Spass gemacht *nein* ☐ *ja* ☐

C EXAMPLES AND DVD CONTENT

Accompanying this thesis and its research is a DVD that contains additional sound and video examples, all related publications and presentations, the LaTeXsources of this document along with all images, as well as the SPSS data files from the respective user evaluations.

Sound Examples.

Video Examples.

Applications.

Documents.

The pdf document of this thesis located in the root folder on the DVD allows a very easy and intuitive access of all examples and additional documents that are contained on the DVD. Through icons at the page border, these examples can directly be accessed and viewed from within the pdf document itself. Four different icons are available and represent *Sound* or *Video* examples, as well as link to external *Applications* and additional *Documents*.

The majority of examples originates from within this research, while additional sound and video examples are included to exemplify related work and to clarify certain ideas and techniques. This chapter provides an overview of the accompanying DVD and references all examples available.

This section as well as the content of the DVD is structured as follows:

EXAMPLES contains 8 folders, in which each folder includes all examples referenced in one chapter.

PUBLICATIONS AND PRESENTATIONS contain all publications and presentations that were prepared throughout the research of this thesis. The publications are grouped into folders and are arranged after conference and submission. Several of these folders also include the presentations held at the respective conferences, as well as additional examples that were used.

THESIS FILES includes all images and the complete LaTeXsource code that was used to prepare and compile this document.

USER EVALUATION SPSS DATA FILES contains the questionnaires and the SPSS data files from the various user evaluations, as well as a link to download a free available version of the *SPSS Legacy Viewer* to view the results of the user evaluations.

C.1 THESIS EXAMPLES

The thesis is accompanied by several sound and video examples that exemplify existing and related work, as well as demonstrate the implemented techniques and prototypes. This section is used to organize all examples available and to provide references for *external* examples. The sound examples are encoded as either PCM wav files or MP3, while all videos are encoded using a DivX[1] or Xvid[2] codec.

All files and executable applications that are contained on the DVD are scanned for viruses and guaranteed to be virus free. When listening to the examples, make sure that no environmental effects, such as added acoustic simulations or the like, are active on your sound hardware. Most examples are best listened through headphones, while some (marked) require a presentation using a stereo speaker setting.

1 http://www.divx.com/
2 http://www.xvid.org/

Chapter1

Chapter 1 introduced the topic of this thesis and motivated the research using several examples of existing work.

- A video of playing the Theremin. (`http://www.youtube.com/watch?v=d5EzKtn2ARE`)
- A video demonstrating Aureal's Wavetracing technology.
- A video showing the ReacTABLE* system in action. (`http://www.youtube.com/watch?v=0h-RhyopUmc`)
- A video demonstrating the graphics-based 3D waveguide implementation from this research.

Chapter3

While Chapter 2 illuminated the research from a very abstract and theoretical perspective, no additional examples are required for this part. The following Chapter 3 introduced the fundamentals of this research and discussed many aspects of the thesis, ranging from sound perception and sound signal processing to music-centered and audio-only computer games. Several additional sound and video files are available, as well as several demonstrations of audio-only computer games. The examples that are required to be presented and perceived using headphones are additionally marked.

- A sound example for a scale illusion (listen through headphones). (`http://philomel.com/musical_illusions/example_scale_illusion.php`)
- A sound example for the perception of phantom words (listen through stereo speakers). (`http://philomel.com/phantom_words/example_phantom_words.php`)
- A sound example for binaural beats (listen through headphones). (`http://www.bwgen.com/`)
- A 3D sound example (listen through headphones). (`http://youtube.com/watch?v=IUDTlvagjJA`)
- An environmental acoustics example (listen through headphones). (`http://www.soundman.de/deutsch/german.htm`)
- A speech synthesis example. (`http://www.research.att.com/~ttsweb/tts/demo.php`)
- A video visualizing the propagation of sound waves.
- A video trailer of the computer game *Silent Hill Origins*. (`http://www.gametrailers.com/player/21634.html`)
- A video of the music-centered computer game *REZ*. (`http://youtube.com/watch?v=A4EFNWe4mCc`)
- A video of the computer game *Metronome*. (`http://www.gamespot.com/pc/adventure/metronome/`)
- A sound demo of the audio-only computer game *Shades of Doom*. (`http://www.gmagames.com/sod.html`)
- A sound demo of the audio-only computer game *Terraformers*. (`http://www.terraformers.nu`)

- A video of the online radio play *Seuss Crane: Detective for Hire*. (http://radio-play.com/seuss/crane)
- A sound sample of the 3D audiobook of Hans Christian Andersen's *"The Nightingale"* (Andersen, 2005).
- A sound sample of the 5.1 audiobook of Jules Verne's *"Journey to the Centre of the Earth"* (Verne, 2005).

Chapter4

In continuation of the previous examples, Chapter 4 concentrated on 2D and 3D auditory display systems and discussed several important aspects. Many of the examples used originate from a publication at the first ICAD conference (Kramer, 1994), while other related and important examples are included as well.

- Seven sound examples demonstrating the principles of auditory Gestalt (Williams).
- Sound examples for a sonification of stock market data (Kramer, 1992).
- Sound examples for static and dynamic beacons (Kramer, 1992).
- Sound examples demonstrating the effectiveness of a 3D auditory display using the application of an air traffic collision avoidance system (Wenzel, 1992; Begault, 1994).
- A sound sample of the *Atmospheric Weather/Works* Project by Polly. (http://andreapolli.com/studio/atmospherics)
- Sound examples demonstrating several audifications of earthquakes and nuclear explosions. (Heyward, 1992).
- Sound examples of earcons for a paint application. (Brewster et al., 1992).
- A sound sample demonstrating a 3D auditory menu system. (http://icad.org/node/402)

Chapter5

The main research started in Chapter 5 with the introduction of 3D virtual auditory environments. The examples that are shown in this chapter still include several important implementations of related work, but the majority of the examples represents auralizations of 3D scenes to acoustically exemplify certain techniques and approaches. These auralizations are spatialized and created using the AM3D sound API, which requires a presentation and perception via regular HiFi headphones (AM3D A/S, 2008).

The listener in these examples is thereby placed at the same location that is indicated in the individual figures, and also rotates around the z-axis to allow a better perception of the auditory scene.

- An auralization of Figure 24b (living room).
- A video demonstrating a musically correct blending of music.
- A sound sample from the album *Pictures at an Exhibition*. (http://www.musopen.com/view.php?type=piece\&id=107)
- An auralization of Figure 26a (normal living room).

- An auralization of Figure 26b (non-realistic sound environment).
- A sound of a Geiger counter. (http://www.mineralab.com)
- A video demonstration of the vOICe system.
- A video demonstrating the sonification of 2D shapes.
- A video demonstrating the sonification of a 3D volumetric data set.
- An auralization of Figure 30b (Soundpipes).
- An auralization of sound and music guides to evoke attraction and repulsion.
- An auralization of Figure 31a (Sonar/Radar).
- An auralization of Figure 31b (Auditory Texture).
- An auralization of Figure 34a (Auditory Cursor).
- An auralization of Figure 34b (Auditory Lens).

Chapter6

Chapter 6 continued the discussions of the previous chapter and directed the research in the area of augmented audio reality. The examples in this section include a demonstration of augmented reality/virtuality, as well as exemplify the principles of augmented audio reality and explain a WiFi-based user positioning technique.

- A video showing examples of augmented reality and augmented virtuality.
- An auralization of Figure 40 (Augmented Audio).
- A video explaining Figure 41 and the functionality of a WiFi-based user positioning.

Chapter7

In Chapter 7 the focus was centered on the authoring and design of 3D virtual auditory environments. Therefore, an authoring framework along with several authoring techniques and guidelines were developed. The videos in this section show the 3D authoring environment applied to the authoring of four basic tasks using the example of an augmented audio reality game.

- A video showing the 3D authoring environment and the creation of a virtual sound source along with the specification of parameters for direction and distance attenuation.
- A video showing the authoring of two auditory textures, as well as the design of object-, time- and input-dependencies.
- A video showing the authoring of a position-dependency (for augmented audio reality).
- A video showing the creation of a 3D ring-based menu system, along with the authoring of auditory textures for the menu items and the specification of an input dependency.

Chapter8

The research in this thesis has shown that all examples require a high-quality auralization combined with a very efficient implementation. Therefore, Chapter 8 conducted additional research in the direction of a GPU-accelerated graphics-based sound rendering and simulation. The examples in this section are comprised of sounds and videos to exemplify the devised techniques and to demonstrate their efficiency.

- A video demonstrating and explaining the GPU-based sound signal processing and filtering.
- A video demonstrating the 3D waveguides implementation of the Cartesian lattice.
- A video demonstrating the 3D waveguides implementation of the BCC lattice.
- A video demonstrating reflection effects in the acoustic ray tracing system.
- A video demonstrating refraction effects in the acoustic ray tracing system.
- A video demonstrating diffraction effects in the acoustic ray tracing system.
- A sound used for the 3D waveguide technique (original sound).
- A sound used for the 3D waveguide technique (low-pass filtered).
- A sound simulation using the 3D waveguides implementation (Cartesian).
- A sound simulation using the 3D waveguides implementation (BCC).

Chapter9

Chapter 9 reviewed the research of the thesis and presented and discussed several areas of application. The examples shown here are very diverse and provide a broad overview of this research and its potential. The majority of the techniques developed in this thesis were examined by user evaluations. This section presents actual examples that were used in these evaluations, as well as shows additional sound and video files to exemplify the developed applications and prototypes.

- A video demonstrating a parallel sonification of stock market data.
- A video demonstrating the sonification of 2D shapes.
- A video showing the sonification of two 3D objects.
- A video demonstrating the sonification of 3D volumetric data sets.
- A video showing the *Sound Stage* for the evaluation of several 3D scene sonification and interaction techniques.
- A video demonstrating the various functions of the auditory lens metaphor.
- A video showing the sonification and interaction with an auditory 3D ring-based menu system.
- A video showing the navigation through a complex 3D auditory environment.
- A video demonstrating both, the soundpipes and the auditory cursor technique.

- A video demonstrating a speech-based interface with the computer game *"Day of the Tentacle"*.
- A sound demo of the audio-only computer game *Shades of Doom*. (http://www.gmagames.com/sod.html)
- A video demonstrating the audiogame *Mosquito*.
- A video demonstrating the audiogame *AudioFrogger*.
- A video demonstrating the audiogame *MatrixShot*.
- A sound demo of the audio-only computer game *Terraformers*. (http://www.terraformers.nu)
- A video of the online radio play *Seuss Crane: Detective for Hire*. (http://radio-play.com/seuss/crane)
- A video demonstrating the auditory adventure game *"The hidden Secret"*.
- Sample data for the evaluation of the bone-conducting headphones.
- A video demonstrating the campus-navigation example.
- A video showing a replay of the augmented audio reality system in the AAR game *"The hidden Secret"*.
- A video showing the interactive audiobook of *"The Pit And The Pendulum"* (Narrative Interaction).
- A video showing the interactive audiobook of *"The Pit And The Pendulum"* (Minigame Interaction).
- A sound demo of the interactive audiobook of *"The hidden Secret"*.
- A video showing the waveguides implementation applied to wavefield synthesis.
- A sound demonstration using virtual HRIR simulations (horizontal plane) (listen through headphones).
- A sound demonstration using virtual HRIR simulations (median plane) (listen through headphones).

The concluding Chapter 10 summarized the thesis and discussed interesting ideas for future research. Although several references were provided, no additional examples are found in this chapter.

C.2 PUBLICATIONS AND PRESENTATIONS

Through the years of research, several publications and articles have been prepared and written along with several presentations that were held at various conferences. Table 16 provides an overview of all publications, as well as directly links to the pdf documents and conference presentations.

Conference	Year	Title
DIGRA	2003	*Game Graphics Beyond Realism: Then, Now, and Tomorrow* (pdf/ppt)
ICAD	2004	*Interacting with Sound: An interaction Paradigm for virtual auditory Worlds* (pdf/ppt)
CGAIDE	2004	*Auditory Game Authoring: From virtual Worlds to auditory Environments* (pdf/ppt)
ICAD	2005	*Leaving the Screen: New Perspectives in Audio-only Gaming* (pdf/ppt)
GCDC	2005	*PS2 Game Development under Linux* (pdf/ppt)
DIGRA	2005	*Playing Audio-only Games: A compendium of interacting with virtual, auditory Worlds* (pdf/ppt)
Graduate Day	2006	*Interacting with Sound: Techniques for interacting with virtual auditory Environments* (pdf/ppt)
Eurographics	2006	*Enhanced Cartoon and Comic Rendering* (pdf/ppt)
TR-2006-4	2006	*HRTF Simulations through acoustic Raytracing* (pdf)
TR-2006-5	2006	*Soundpipes: A new way of Path Sonification* (pdf)
TR-2006-8	2006	*Flexible Film: Interactive Cubist-style Rendering* (pdf)
AudioMostly	2006	*Authoring of 3D virtual auditory Environments* (pdf/ppt)
AudioMostly	2006	*Composition and Arrangement Techniques for Music in Interactive Immersive Environments* (pdf/ppt)
ICMC	2006	*Waveguide-based Room Acoustics through Graphics Hardware* (pdf/ppt)
TIDSE	2006	*Interactive Audiobooks: Combining Narratives with Game Elements* (pdf/ppt)
Cost ConGAS	2007	*Interaction with Sound in auditory Computer Games* (pdf)
DAFx	2007	*Ray Acoustics using Computer Graphics Technology* (pdf/ppt)
AudioMostly	2007	*Evolution of Interactive Audiobooks* (pdf/ppt)
AudioMostly	2008	*A Musical Instrument based on 3D Data and Volume Sonification Techniques* (pdf)

Table 16: Thesis Publications and Presentations.

C.3 THESIS FILES

This thesis was prepared using LaTeX and compiled using MikTeX 2.4.1779. The *Thesis Files* folder on the DVD contains the complete source code and all necessary files to compile this thesis. The style used in this document is a slight variation of the *Classic Thesis* style developed by Miede (Miede, 2007).

The Root Folder contains the main tex file (diss.tex), as well as the style files and the individual bibtex sources. The additional subfolders are organized as follows:

APPENDIX The tex files of the appendices of the thesis.

BACKMATTER The *backmatter* of the thesis, ie. listings, bibliography, index, acronyms and declaration.

CHAPTER The main tex files for the chapters of the thesis.

FRONTMATTER The *frontmatter* of the thesis, ie. title pages, table of contents, notation, acknowledgements, abstract, dedication and publications.

IMAGES All image data used for the figures in this thesis.

C.4 QUESTIONNAIRES AND SPSS DATA FILES

Several user evaluations have been performed throughout this research to evaluate and assess the designed techniques and the implemented systems. All evaluations were based on user observations and questionnaires, but also sometimes employed user log-files to determine the user's performance and to estimate the system's functionality. The DVD contains all of the questionnaires used, as well as the SPSS data files from the evaluation. *SPSS* is a powerful data mining and statistical analysis software that is often used to analyze user evaluations (SPSS Inc., 2008). In order to inspect the SPSS data files, either a working copy of SPSS, or the *SPSS Legacy Viewer*[3] is required (SPSS Inc., 2008).

3 http://support.spss.com/Student/Utilities/SPSS/LegacyViewer/readme.html

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ACRONYMS

2D	Two Dimensional
3D	Three Dimensional
AAR	Augmented Audio Reality
AD	Auditory Display
AGP	Accelerated Graphics Port
API	Application Programming Interface
AR	Augmented Reality
A/S	Analogic/Symbolic (Continuum)
AV	Augmented Virtuality
AUI	Auditory User Interface
BCC	Body Centered Cubic (Lattice)
BEM	Boundary Element Methods
BRDF	Bidirectional Reflection Distribution Function
CAVE	Cave Automatic Virtual Environment
CC	Cubic Cartesian (Lattice)
CD	Compact Disc
Cg	C for Graphics
CPU	Central Processing Unit
DOF	Degree Of Freedom
DSP	Digital Signal Processor
DVD	Digital Versatile Disc
EAX/EFX	Environmental Audio/Effects Extension
eg.	*exempli gratia* For Example
FCC	Face Centered Cubic (Lattice)
FBO	Framebuffer Object
FEM	Finite Element Methods
ie.	*id est* That Is
(I)FFT	(Inverse) Fast Fourier Transformation
FIR	Finite Impulse Response
fps	Frames Per Second
GLSL	Graphics Library Shading Language

GPGPU	General Purpose computations using a Graphics Processing Unit
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HCI	Human Computer Interaction
HiFi	High Fidelity (Audio)
HLSL	High Level Shading Language
HRIR	Head-related Impulse Response
HRTF	Head-related Transfer Function
IR	Impulse Response
MR	Mixed Reality
NPR	Non-photorealistic Rendering
NRS	Non-realistic Sound Presentation
OpenAL/EFX	Open Audio Library plus Environmental Effects Extension
OpenGL	Open Graphics Library
OpenSG	Open Scene Graph
PC	Personal Computer
PCIe	Express Peripheral Component Interface
PCM	Pulse Code Modulation
PSP	PlayStation Portable
RIR	Room Impulse Response
SDL	Simple Direct Media Layer
SLI	Scalable Link Interface
SPSS	*Statistical Package for the Social Sciences* – A statistical data analysis software.
UI	User Interface
UMD	Universal Media Disc
UML	Unified Modeling Language
VAE	Virtual Auditory Environment
VE	Virtual Environment
VR	Virtual Reality
VRML	Virtual Reality Markup Language
VRPN	Virtual Reality Peripheral Network
VTK	Visualization Tool Kit
WiFi	Wireless Fidelity – Wireless Local Area Network
XML	Extended Markup Language

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DECLARATION

I herby declare that this thesis was complied solely by myself and only with the the references marked and cited.

Magdeburg, September 2008

Niklas Röber