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INVESTIGATIONS OF MULTI-CHANNEL AURALIZATION TECHNIQUE FOR SOLO INSTRUMENTS AND ORCHESTRA

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ABSTRACT
Computer modeling of room acoustics is a useful tool in the design of acoustically sensitive spaces and an important outcome from these programs is auralizations. This study examined the perceived changes in realism and source width when listening to multi-channel auralizations compared to single channel auralizations for both solo instruments and a full orchestra. The first experiment, which examined subjective judgments of auralizations made from solo instruments, showed that perceived realism increased as the number of channels was increased from one to four to thirteen, while the relationship between source width and number of channels was less clear. In the second experiment, an orchestra was auralized in four different ways: individual instrumental sections with (i) one channel each and (ii) five channels each; and the entire orchestra emanating from (iii) a single omni-directional source and (iv) a surface source. Listeners' judgments comparing all of the auralizations showed improved perceived realism with the multiple sources (i, ii) compared to the surface source, and wider source width with the multiple sources compared to the single omni-directional source. No improvement in either realism or source width was found as the number of channels was increased from one to five for the individual sources.

INTRODUCTION
Computer modeling of room acoustics assists in the design of acoustically sensitive spaces, by predicting room acoustic parameters, such as reverberation time, and also by auralizations – a virtual reproduction of how the space might sound. Auralizations can assist with detecting unwanted sounds in the space such as harsh echoes or too much late energy. The traditional method for creating an auralization involves convolving the binaural room impulse response (BRIR) with a single channel anechoic recording of a short melody. The primary disadvantage of this method is that there are limited means to incorporate the source directivity, or the source's directional characteristics, into the auralization, which reduces the accuracy of the reproduction. This study focuses on a different method of creating auralizations, which better incorporates source directivity and thus improves the accuracy of the reproduction. The method requires multi-channel anechoic recordings of short melodies and calculating BRIRs for each channel representation.

Many international round-robin studies have been conducted over the past decade to aid in the improvement of computer software for modeling room acoustics [1-4]. However, these studies have focused on accurately predicting room-acoustics parameters and not specifically on auralizations. The roots of auralizations can be traced back to Schroeder [5], but were more formally defined in 1993 by Kleiner et al [6]. Since that time, the use of auralizations as a tool has improved and become more practical due to advances in computing power. Much work is still needed to produce more accurate auralizations, which is the motivation for this study.

The importance of source directivity in computer modeling has been investigated in the last two decades. Giron's dissertation [7] focused on various methods of modeling source directivity, including inverse spherical harmonic transforms. In 2004, Wang and Vigeant [8] showed the effects of including source directivity into computer models both in terms of objective differences in room acoustics parameters and subjective judgments of auralizations. Significant differences in predicted reverberation time and clarity index were found between the impulse responses from omni-directional and directional sources for specific source and receiver combinations. Subjective judgments by subjects revealed measurable differences in perceived reverberance and realism. Otondo and Rindel [9] showed similar results in their study of the effects of changes in reverberation time and sound pressure level distributions over the entire audience area of a hall. Listeners compared auralizations made with average and specific directivities and the results showed differences in perceived loudness and sometimes perceived reverberance.

The method of multi-channel auralizations was first introduced by Otondo and Rindel in 2005 [10]. They obtained thirteen-channel anechoic recordings of several instruments, with the recording configuration as shown in Figure 1. Subjective listening tests were conducted comparing auralizations with one, two, five and ten channels on two properties: spaciousness and naturalness of timbre. Results revealed a significant improvement in naturalness of timbre as the number of channels increased.

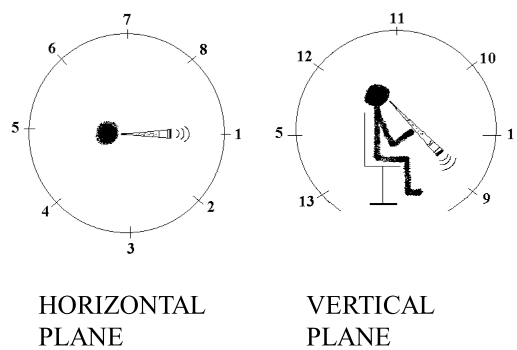

Figure 1: Multi-channel anechoic recording configuration (adapted from [10]).

The purpose of the present study was to investigate further the multi-channel auralization method. The results of two experiments examining listener's subjective judgments will be presented. The first experiment included multi-channel auralizations of solo instruments, whereas the second experiment included multi-channel, multi-source auralizations of an entire orchestra.

EXPERIMENT 1 – MULTI-CHANNEL AURALIZATIONS OF SOLO INSTRUMENTS

The purpose of the first experiment was to investigate the effectiveness of the multi-channel auralization method. With previous methods, auralizations were created by convolving single channel anechoic recordings with the impulse response calculated from the measured source directivity. For this experiment, multi-channel anechoic recordings were used to model the directivity, not the measured directivity data. The hypothesis of this investigation was that the auralizations would sound more realistic as the number of channels in the auralizations was increased from one to four to thirteen.

Method – experiment 1

The auralizations were created using ODEON v6.5, a room-acoustics software program. The geometry used for the calculations was a model of a small auditorium. Auralizations were created by first dividing an omni-directional source into the number of recording channels. For example, to create a four-channel auralization, an omni-directional source was divided into quadrants and the BRIR was calculated for each "quadrant" source. Each BRIR was then convolved with the appropriate recording channel (i.e., the front quadrant source BRIR was convolved with the front recording channel). The four auralizations were mixed in ODEON to create the final multi-channel auralization. For the one-channel case, the entire omni-directional source was used to calculate the BRIR, while for the thirteen-channel case, the omni-directional source was first divided into thirteen equal sections.

The multi-channel anechoic recordings used in this experiment were obtained from Otondo and Rindel at the Technical University of Denmark (10). Three instruments were included in the investigation with varying directivities: the trombone (highly directional), the flute (moderately directional), and the violin (least directional).

Listeners were tested at the University of Nebraska in a quiet office setting. The 30 subjects were presented the auralizations over headphones in random order. An average head-related-transfer-function was used in the creation of the auralizations. The test subjects had normal hearing, with hearing thresholds below 25 dB hearing level. The subjects were required to have a minimum of three years of musical training, and had on average 10 years of formal training and 14 years of experience. The subjects were asked to rate each auralization on seven-point scales for realism, where 1 represented 'very unrealistic' and 7 represented 'very realistic', and source width, where 1 represented 'very narrow' and 7 represented 'very wide'.

Analysis of subjective judgments – experiment 1

The listeners' subjective judgments were analyzed using a repeated-measures analysis of variance (ANOVA). For the first independent variable of realism, a significant main effect of channel was found, $F(2,58)=16.59$, $p < .0001$. Average ratings for one, four and thirteen channels were 4.6, 5.0, and 5.5, respectively. Further ANOVA tests revealed significant differences between the one- and thirteen-channels ratings, $F(1,29)=27.88$, $p < .0001$, and between the four- and thirteen-channel, $F(1,29)=11.87$, $p < .0018$. Therefore, as the number of channels was increased, the perceived realism increased.

The results for source width are more complicated. Neither a significant main effect of channel or instrument were found; however a significant interaction between the two variables was found, $F(4,116)=20.49$, $p < .002$, as shown in Figure 2. The most directional instrument, the trombone, was perceived to become narrower as the number of channels increased. However, the results for the flute, a moderately directional instrument, revealed subjects found no change in source width from one to four channels, but then a significant increase from four to thirteen. For the violin, the least directional instrument, the source width was perceived to increase when the channels were increased from one to four, with no change from four to thirteen. With such varying results, there is no clear relationship between perceived source width and number of channels. The perception of source width as a function of the number of channels varies based on instrument type, and thus source directivity.

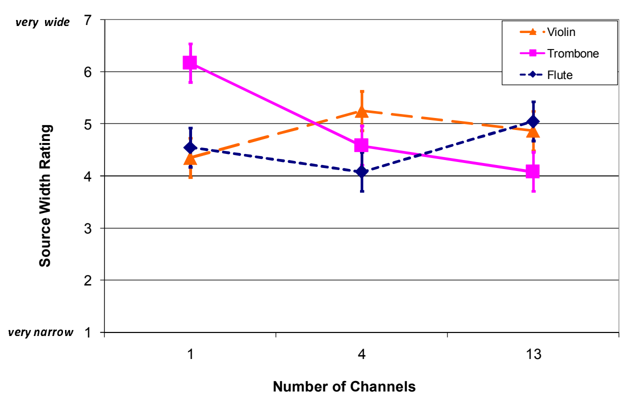

Figure 2: Results from Experiment 1 – subjective ratings of source width as a function of auralizations made with an increasing number of channels with three different solo instruments.

EXPERIMENT 2 – MULTI-CHANNEL MULTI-SOURCE AURALIZATIONS OF AN ORCHESTRA

The previous experiment examined multi-channel auralizations of solo instruments; however, the majority of performances in a performing arts center involve an ensemble of musicians, including a full orchestra. Researchers at the Technical University of Denmark obtained five-channel anechoic recordings of each individual instrumental part for two symphonies: Mozart's Symphony No. 40, G minor, 1st movement and Brahms' Symphony No. 4, 3rd movement. Of the five channels, four were in the horizontal plane (positions 1, 3, 5, and 7 as shown in Figure 1) and the fifth was directly above the musician (position 11). These recordings were edited into abbreviated portions of each piece to be used to create auralizations. The orchestra was simulated in four different ways: 1) single omni-directional source; 2) the stage acting as a surface source; 3) individual one-channel sources; and 4) individual five-channel sources. Listening tests were conducted to determine if subjects could detect differences in realism and source width for the various configurations. The hypothesis was that the multi-source configurations would be rated as more realistic and wider.

Method – experiment 2

The auralizations were created using BRIRs calculated for a receiver in a model of Vienna's Grosser Musikvereinssaal using Odeon v8.5. The hall was studied in two configurations. First, the model was calibrated using measurements in the actual hall with an average mid-frequency reverberation time (RT) of 2.1 s. In the second case, absorption was added in the model to reduce the average RT to 1.5 s. An anechoic mix of the entire orchestra was required for the convolutions with the single omni-directional source and the stage surface source. For the one- and five-channel multi-source auralizations, the configuration of the instruments was as shown in Figure 3. For illustration purposes, the instruments are shown facing straight out towards the audience, but the sources were oriented towards the conductor. Individual sources were used to represent the string sections, with the sound power of the sources increased according to the number of instruments represented.

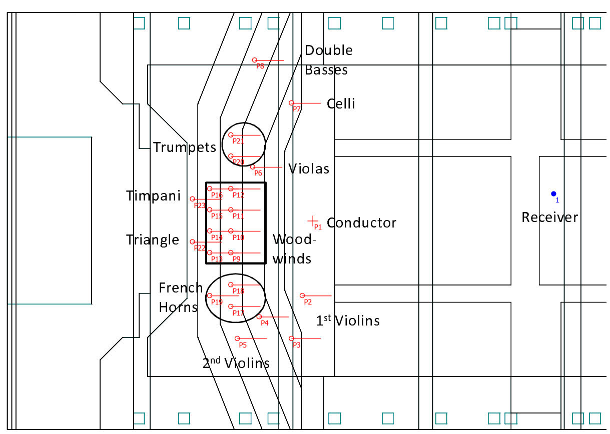

Figure 3: Section view of the stage of the model of the Grosser Musikvereinssaal illustrating the source positions used in the multi-source single and five-channel configurations.

Subjects were recruited from the University of Nebraska community and were again required to have a minimum of three years of musical training and normal hearing. In total, there were 33 subjects, with an average of 10 years of formal instruction and 13 years of experience. The auralizations were presented to subjects over headphones in random order and subjects were asked to rate the realism and source width on seven-point rating scales, as in the first experiment.

Analysis of subjective judgments – experiment 2

As in Experiment 1, a repeated-measures ANOVA was used to analyze the results from the listening tests. The overall results obtained from the two hall configurations were very similar. A sample of results for each configuration will be discussed.

The results for realism for the original hall configuration (Fig. 4) showed a significant main effect of source type, $F(3,96)=14.29$, $p < .0001$. Overall, subjects rated the multiple one-channel and five-channel source configurations as sounding significantly more realistic that the surface source configuration. There was no increase in the realism ratings when the number of channels in the multi-source configuration was increased from one to five.

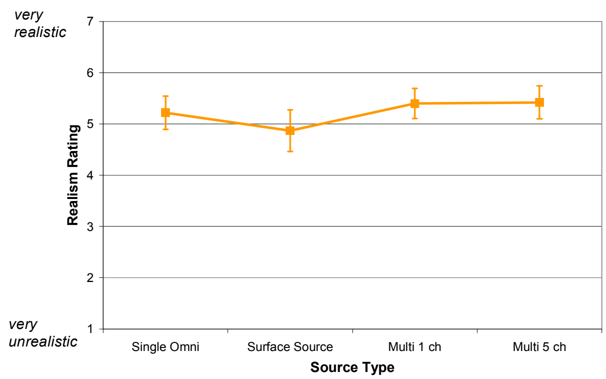

Figure 4: Results from Experiment 2 – subjective ratings of **realism** as a function of auralizations made with different source types which represent a full orchestra.

For the modified hall configuration, a significant main effect of source type on source-width ratings was found, $F(3,96)=8.84$, $p < .0001$, as shown in Figure 5. The auralizations with the multi-source configurations were rated as wider than the single omni-directional source, as hypothesized. However, subjects did not perceive the multi-source five-channel case to sound wider than the multi-source one-channel case. These results indicated no significant improvement was found for multi-channel auralizations when multiple sources were used.

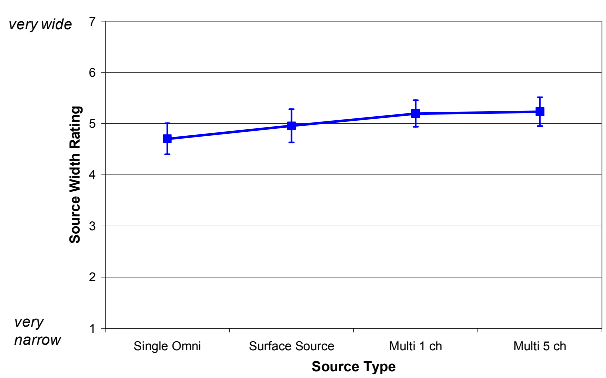

Figure 5: Results from Experiment 2 – subjective ratings of **source width** as a function of auralizations made with different source types which represent a full orchestra.

CONCLUSIONS

The results from two experiments examining subjective judgments of room acoustics have been presented. Experiment 1 examined multi-channel auralizations of solo instruments and Experiment 2 examined multi-channel multi-source auralizations of an orchestra. Results from the first experiment showed that as the number of channels used in the auralizations was increased, the perceived realism increased, as hypothesized. However, the relationship between number of channels and source width is less clear, as there is an interaction with instrument. In Experiment 2, auralizations made with multiple sources were rated as sounding more realistic compared to auralizations created from a surface source, and were perceived as wider compared to auralizations generated with a single omni-directional source. No improvement was found for the multi-channel multi-source configuration over the single channel multi-source configuration. The subtle differences between these two auralization types may have been masked when contrasted against the auralizations made with a single omni-directional and surface source. Further work on the effects of different orchestral arrangements, with phase-shifted string sections, is planned to investigate in more detail the effects of the multi-channel multi-source technique.

References:

[1] M. Vorländer: International round robin on room acoustical computer simulations. 15th International Congress On Acoustics, Trondheim, Norway, 26 – 30 June (1995)

[2] I. Bork: A comparison of room simulation software – The 2nd round robin on room acoustical computer simulation. Acustica **86, No.6** (2000) 943–956

[3] I. Bork: Report on the 3rd round robin on room acoustical computer simulation – part I: measurements. Acta Acustica united with Acustica, **91, No.4** (2005) 740–752

[4] I. Bork: Report on the 3rd round robin on room acoustical computer simulation – part II: calculations. Acta Acustica united with Acustica, **91, No.4** (2005) 753–763

[5] M. R. Schroeder: Digital simulation of sound transmission in reverberant spaces. Journal of the Acoustical Society of America **47, No.2** (1970) 424–431

[6] M. Kleiner, B. I. Dalenback, and P. Svensson: Auralization – an overview. Journal of the Audio Engineering Society **41, No.11** (1993) 861–875

[7] F. Giron: Investigations about the directivity of sound sources. Ph.D. dissertation, Ruhr-Universität Bochum (1996)

[8] L. M. Wang, M. C. Vigeant: Objective and subjective evaluation of the use of directional sound sources in auralizations. 18th International Congress on Acoustics, Kyoto, Japan **IV** (2004) 2711–2714

[9] F. Otondo, J. H. Rindel. The influence of the directivity of musical instruments in a room. Acta Acustica united with Acustica **90, No.6** (2004) 1178–1184

[10] F. Otondo, J. H. Rindel: A new method for the radiation representation of musical instruments in auralizations. Acta Acustica united with Acustica, **91, No.5** (2005) 902–906