Proceedings of The Institute of Acoustics

THE PSYCHOACOUSTICAL BACKGROUND OF AUDITORY SPACIOUSNESS

Jens Blauert

Lehrstuhl für allgemeine Elektrotechnik und Akustik
Ruhr-University, D-4630 Bochum, Postbox 10 21 48

Auditory spaciousness has recently been shown to be an important component of the qualification of a hall for musical performances (e.g. BARRON 1974, GOTTLOB 1973). In this paper we describe a model of binaural interaction which is based on psychoacoustical evidence. The model gives some indication of how auditory spaciousness may be perceived by the hearing system. Application of the model may lead to a method for objective evaluation of auditory spaciousness.

1. INTRODUCTION

A person entering a hall immediately develops an intuitive auditory impression of the type and the dimension of the hall. One component of this auditory spacial impression is the so called auditory "spaciousness". Spaciousness, in this sense, denotes a characteristic spatial spreading of the auditory events, i.e., that they fill a larger amount of space than is defined by the visual contours of the ensemble of sound sources, e.g. an orchestra (Fig. 1).

Auditory spaciousness is a product of binaural hearing. In the following we describe a model of binaural signal processing which, consequently, may also be used to explain the phenomenon of spaciousness.

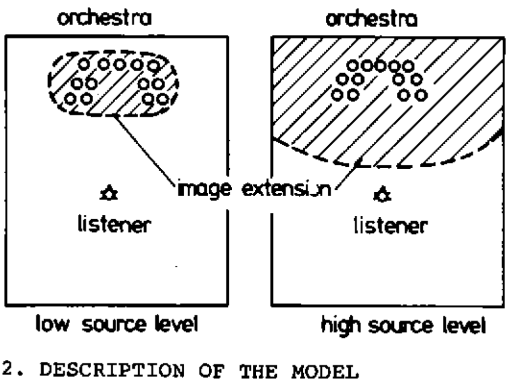

Fig. 1: Auditory spaciousness: the percieved extent of the auditory events is larger than the space defined by the visual contours of the sound sources (after KUHL 1977)

2. DESCRIPTION OF THE MODEL

A rough outline of our model is given in Fig. 2. The two input signals to the model are each fed to a set of filters which model the external ear transfer characteristics. Typically these external ear filters are realized by means of a dummy head. The external ear filters are connected to the middle ear filters which deliver their output to inner ear models. The inner ear models have two functions, viz., (a) running Fourier analysis and (b) signal conversion to nerve firing patterns.

In a simple version of the model, the running Fourier analysis is performed by a set of adjacent bandpass filters, each having a frequency response shaped after (inverted) tuning curves. Each of the cochlea filters is followed by a receptor-neuron firing model. In its simplest form, the firing model consists of a half-wave rectifier followed by a first order low pass with a 800 Hz cut-off frequency. This means that we make the following simplified assumptions to model the nerve firing patterns: At low frequencies the firing probability is proportional to the instant value of the positive signal half-wave. At high frequencies firing probability is no longer synchronized to the fine structure of the signal waveform but proportional to the envelope.

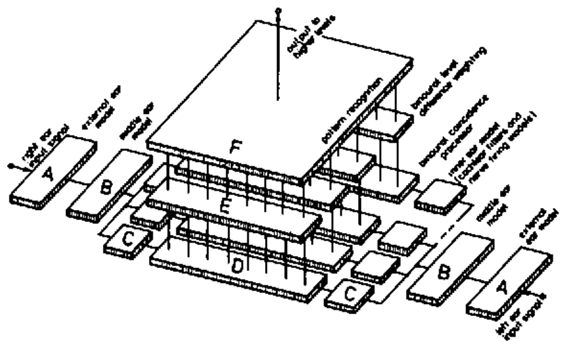

Fig. 2: Block diagramm of a model of binaural interaction which can, among others, be used to evaluate auditory spaciousness

Fig. 3 schematically depicts the most relevant part of the binaural processing, i.e. the model component that deals with interaural arrival time differences. There is one binaural processor element for each frequency band under evaluation. In principle, each binaural processor element performs a running cross-correlation on its two input signals. This is carried out by two tapped delay lines which are connected by multiplier cells at each tap (JEFFRESS 1948). The output of the array shown in Fig. 2 can be regarded as a two dimensional running cross-correlatogram $R(f,\tau,t)$.

The running cross-correlatogram is modified in a further block of the model to include the effect of interaural level differences (Fig. 4). This is accomplished by weighting the cross-correlation function in each band by means of a bell-shaped weighting function whose position on the τ-axis is governed by the instantaneous level difference in each particular band (STERN + COLBURN 1978). Thus we gain a weighted running cross-correlatogram as an output of our model. It is assumed that the amount of auditory spaciousness can be extracted from this running correlatogram, e.g. by means of pattern recognition (LINDEMANN 1982).

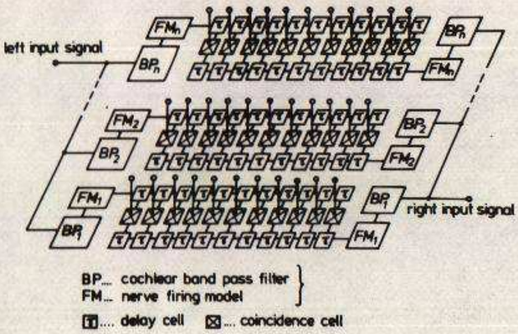

Fig. 3: Outline of a binaural processor which performs some kind of a running interaural cross-correlation analysis on its two input signals

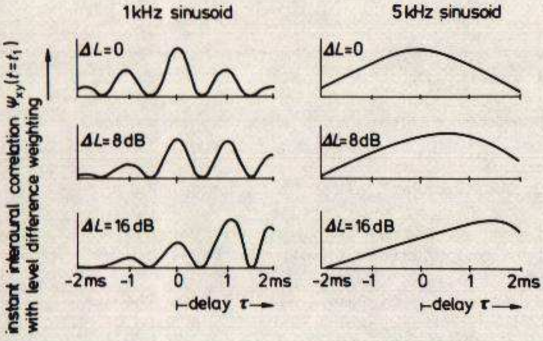

Fig. 4: Schematic representation of the weighting of interaural cross-correlation functions according to the instanteneous interaural level differences

3. RESULTS

For illustrative purposes in Fig. 5 two typical results are given to show the characteristic patterns that are associated with spaciousness. The left panel depicts an instant weighted correlatogram of a musical chord played by a loudspeaker in an anechoic chamber, right in front of the dummy head. The correlatogram shows a series of main peaks on the $\tau = 0$ line and further side peaks in a symmetric arrangement with respect to this line. The right panel depicts the situation when two additional loudspeakers to the side of the dummy head radiate delayed versions of the original signal in addition to the undelayed frontal signal. The effect of the lateral energy is a clearly visible shift of the individual peaks to either side. The shift is different with respect to direction and amplitude in each frequency band.

We hypothesize that a measure of spaciousness can be deduced from the amplitude and speed of those peak-shifts. At the present time work is going on to evaluate the contribution of each frequency band to total spaciousness.

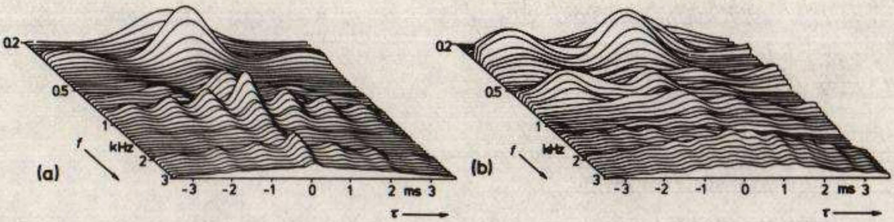

Fig. 5: Instanteneous weighted running interaural cross-correlatograms presenting a musical chord: (a) direct frontal sound only, no lateral reflections, no spaciousness; (b) direct frontal sound plus lateral reflections, distinct spaciousness.

1. BARRON, M. 1974 Dissertation, Univ. Southampton. The effect of early reflections on subjective acoustical quality in concert halls.
2. GOTTLOB, D. 1973 Dissertation, Univ. Göttingen. Vergleich objektiver akustischer Parameter mit Ergebnissen subjektiver Untersuchungen an Konzertsälen.
3. JEFFRESS, L.A. 1948 J. Comp. Physiol. Psych. 61, 468-486 A place theory of sound localization.
4. KUHL, W. 1978 Acustica 40, 167-168. Räumlichkeit als Komponente des Raumeindrucks.
5. LINDEMANN, W. 1982 in: Binaural effects in normal and impaired hearing (O.J. Pedersen + T. Poulsen, Eds.), Scand. Audiol. Suppl. 15, 147-155. Evaluation of interaural signal differences.
6. STERN, R.M. + COLBURN, H.S. 1978 J. Acoust. Soc. Amer. 64, 127-140. The theory of binaural interaction based on auditory-nerve data IV, A model for subjective lateral position.

Note: An animated series of computer plots of weighted cross-correlatograms (trick film) will be shown during the session for further elucidation. The author is indepted to W. LINDEMANN for supplying this film.