Relationship between auditory information processing and perceptual evaluations of musical instruments

Miriam N. Valenzuela

InPersonIC Corporation, D-81825 Munich, Germany, Email: miriam.valenzuela@inpersonic.com

Introduction

From a system-theoretical point of view, the main objective of the human sensory system, when perceptually evaluating musical instruments, is to extract the signal attributes which are resistant to changes due to transmission and are therefore information-carrying. The processes involved are described in the following hierarchical model.

The hierarchical model

Scientific investigations concerning cognitive processes leave no doubts that a hierarchical organization is involved in sensory information acquisition. A general model proposed by Terhardt [4] emphasizes that the knowledge-based hierarchical processing of sensory information begins at the periphery. Based on this concept and including common experimental data from various investigators obtained with different types of sound signals such as speech, music, and environmental events, a model has been developed that describes some of the different processes involved in the perceptual evaluation of musical instruments. In the following, the model is presented in two parts: the first part focuses on auditory processes; the second part highlights the processes involved in perceptual evaluations of musical instruments.

Auditory information processing

As shown in Figure 1, a sound signal is transformed into increasingly abstract, more comprehensive perceptual objects through a series of knowledge-based processes. The large amount of information contained in the sound signal is thus reduced to the information that is the most relevant for responding to a specific task. The attention is set to the highest level of abstraction containing the information.

The knowledge involved in the decision-processes of the lower levels includes primarily knowledge about how a sound signal is changed due to its transmission through air, or in other words, which signal parameters are resistant to such transmission changes, and thus information-carrying. Independent of the type of sound signal, the same characteristics of the ear, known from psychoacoustics, are employed in the process of acquiring the relevant information. Such typical ear characteristics are, for example, time-and frequency selectivity, masking patterns, the phenomenon of spectral dominance (outstanding importance of information contained in the frequency region from about 500 Hz to 1.5 kHz), and the grouping rules of the "Gestalt" principles. Because the knowledge employed does not primarily depend on the type of sound signal (although apparently different types of sounds will produce different sets of objects), it is obvious that, in comparable contexts, similar perceptual attributes will characterize the auditory evaluations of different types of sounds [1, 2, 6].

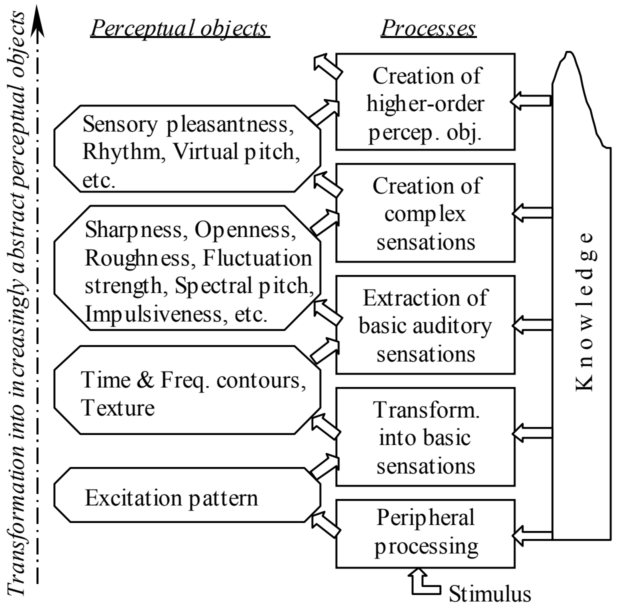

Figure 1: Schematic model of auditory information processing. Perceptual objects mentioned at each level are potential candidates for auditory evaluations of instruments.

Evaluation of musical instruments

The experimental response that a subject gives when evaluating a musical instrument is the result of a series of evaluation and decision processes at various levels of the hierarchy. In addition to auditory cues, cues from other sensory modalities (e.g. sense of touch or vision) and prior knowledge can be taken into consideration. In general, a number of perceptual objects distributed over the hierarchy will contain the relevant information for the evaluation of an instrument. The ranking of the objects in terms of the relevance of their information will change as a function of context, i.e. (a) what type of signal is presented to the subject (does he play the instrument himself; is he presented with the sound of a single note or with a whole musical phrase; etc.), and (b) what is the task that the subject is requested to respond to (is he asked to identify an instrument or to make a quality judgement, etc.).

Figure 2 shows the processes that, depending on the context, are involved in providing the relevant information for (a) recognizing an instrument as a member of a family of musical instruments, (b) identifying the characteristic attributes of a specific instrument, (c) judging the quality of an instrument, and (d) estimating dissimilarities due to physical changes in an instrument or dissimilarities between two different instruments. The basis for these perceptual evaluations are knowledge-based decision processes that by means of discrimination create a set of distinctive attributes for each kind of sensory modality. In principle, the discrimination processes reduce the information obtained in the different hierarchical levels of the corresponding sensory information processor to the perceptual objects (distinctive attributes) that are needed to discriminate two stimuli. The stimuli can be either two signals that are presented to the subject for comparison, or one signal that is presented and prior knowledge acquired over time about musical instruments, which is distributed over the hierarchies.

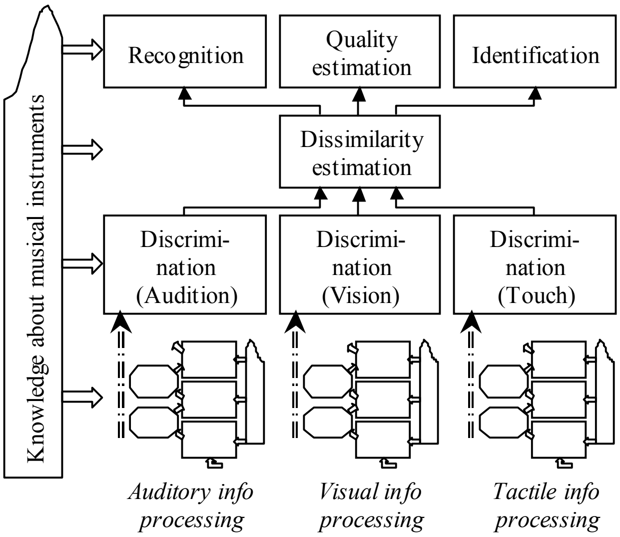

Figure 2: Schematic model for perceptual evaluations of musical instruments.

The context-dependent estimation of dissimilarities is based on the set of distinctive attributes of the relevant sensory modalities. For any sensory modality, the attention is pre-set to the highest level of abstraction that contains the substantial information. If the attention has to be switched to lower levels in order to detect the distinctive attributes, a larger effort is needed and a small dissimilarity estimation results. This implies that the most prominent distinctive attributes dominate the dissimilarity estimate, which is confirmed in different experimental studies [1, 5, 6].

Recognition, identification and quality judgments are based on the set of perceived dissimilarities. The kind of instrument is recognized if the dissimilarities are, on the one hand, small when compared to the characteristic attributes stored as prior knowledge for that kind of instruments, and on the other hand, large when compared to characteristic attributes stored for other kinds of instruments. In order for the identification of a specific instrument to occur, the dissimilarities among several instances of that one instrument must be less than the dissimilarities between different instruments of that same kind. Quality estimations of instruments are based on dissimilarity estimates derived from comparisons with knowledge-based references for quality optimums. Only the most prominent dissimilarities between the stimulus and the knowledge-based references have an influence on the quality estimation [5].

Putting the model into practice

One essential implication of the hierarchical processing is that the output of each processing level is at the same time the input to the next higher level. Therefore, when implementing a calculation algorithm for one of the processing levels, it is important to make sure that the calculation algorithms of the lower levels are correct. For example, using a Fast-Fourier-Transformation as peripheral processing to calculate spectral pitch does not work because it does not correctly take the characteristic time- and frequency-resolution of the ear into account [6]. Even using an aurally adequate sound signal representation, as proposed by Terhardt, Heinbach and Mummert [4] (and lately implemented in the commercial product VIPER), to identify the perceptually relevant vibration modes of an instrument, does not work properly if the different spectral masking patterns of tonal and noisy components are not taken into account in the peripheral processing [5, 6].

According to the model, the ranking of perceptual objects in terms of the relevance of their information changes as a function of context. This implies that there is not one single correct set of attributes that is sufficient for the perceptual evaluation of musical instruments. Depending on the experimental situation, for example, the chosen type of music influences the quality judgments of pianos [3]. A further implication, however, is that by eliminating distinctions between higher-level objects through limitations of the context, the relatively large set of unique objects evoked for specific contexts is reduced to a smaller core of distinctive attributes which are based on the basic perceptual sensations. For example, when limiting the context to only audible comparisons between single tones of instruments, dissimilarity and quality estimations are primarily based on such basic auditory sensations as, for instance, sharpness, openness, impulsiveness, fluctuation strength, etc. [1, 2, 5, 6]. Identification and recognition of single musical tones also involve mainly basic auditory sensations such as spectral pitch, virtual pitch and impulsiveness [2, 6].

In summary, the model includes a number of sufficiently well-defined features which are confirmed by comparison with observations and experimental data. Although the model leaves many aspects and details undefined, it provides a conceptual framework that facilitates investigations in the area of musical acoustics.

References

[1] K. Benedini: Ein Funktionsschema zur Beschreibung von Klangfarbenunterschieden. Biol. Cyb. **34** (1979) 111-117.

[2] J.M. Grey: Multidimensional perceptual scaling of musical timbres. J. Acoust. Soc. Am. **61** (1977) 1270-1277.

[3] A.F. Meyer: Akustische Untersuchungen an Klavieren, Teil II. Das Musikinstrument **29** (1980) 1432-1441.

[4] E. Terhardt: Akustische Kommunikation. Springer, Berlin, 1998.

[5] M.N. Valenzuela: Untersuchungen und Berechnungsverfahren zur Klangqualität von Klaviertönen. Utz, München, 1998.

[6] M.N. Valenzuela: Zur Rolle des Gehörs bei akustischen Untersuchungen an Musikinstrumenten. Beiträge zur Vibro- und Psychoakustik 1/99, Neubiberg, 1999.